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Identification and Analysis of National Airspace System Resource Constraints

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Introduction

This analysis is the deliverable for the Airspace Systems Program, Systems Analysis Integration and Evaluation Project Milestone for the Systems and Portfolio Analysis (SPA) focus area **SPA.4.06 Identification and Analysis of National Airspace System (NAS) Resource Constraints and Mitigation Strategies.**

"Identify choke points in the current and future NAS. Choke points refer to any areas in the en route, terminal, oceanic, airport, and surface operations that constrain actual demand in current and projected future operations. Use the Common Scenarios based on Transportation Systems Analysis Model (TSAM) projections of future demand developed under SPA.4.04 Tools, Methods and Scenarios Development. Analyze causes, including operational and physical constraints."

The NASA analysis is complementary to a NASA Research Announcement (NRA) "Development of Tools and Analysis to Evaluate Choke Points in the National Airspace System" Contract # NNA3AB95C awarded to Logistics Management Institute, Sept 2013.

Motivation

Identification of the major choke points in the NAS allows targeted research and development of concepts and technologies to increase capacity where most needed. This analysis by NASA focuses on understanding potential future capacity shortfalls based on projections of future demand for air transportation. The corresponding NRA is broader in scope and includes investigation of current day choke points, soliciting input from a comprehensive set of NAS stakeholders.

Technical Approach

The approach taken in this study is to use TSAM to predict unconstrained trip demand and NASA's Airspace Concept Evaluation System (ACES) to investigate the impact on the future NAS.

Transportation Systems Analysis Model

TSAM is a nationwide transportation-planning model to forecast intercity travel behavior in the United States. TSAM is currently under development by NASA Langley Research Center and Virginia Polytechnic Institute's Air Transportation Systems Laboratory. Figure 1 shows the components of the model.

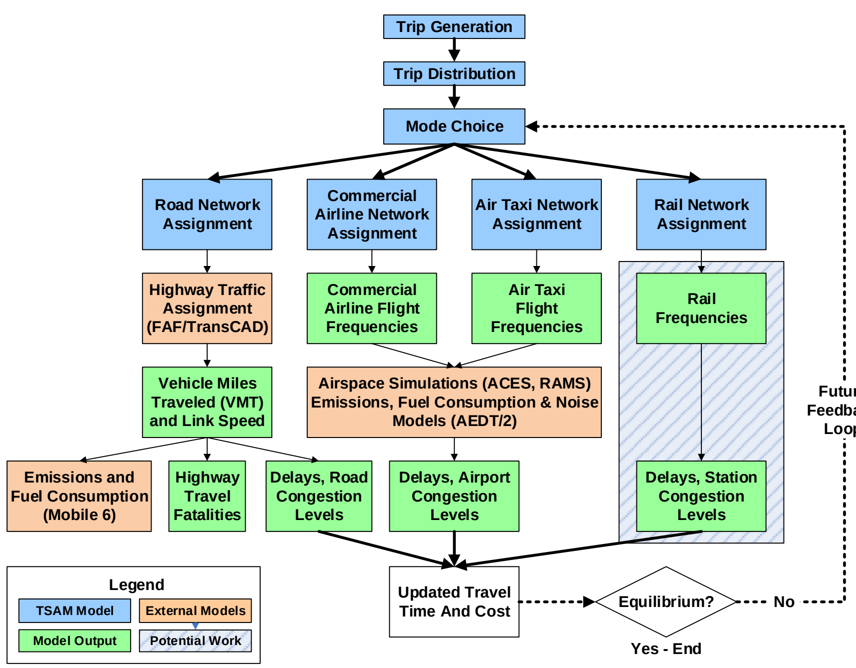

Figure 1. Transportation Systems Analysis Model

TSAM predicts the number of trips of more than 100 miles between each of the 3076 counties in the contiguous United States. The model uses socio-economic and demographic data to make projections of future travel demand for trips by available modes; these are travel by air, road and rail, or any new mode modeled with performance and cost data, e.g. on-demand air service. TSAM projects international travel demand by air between the contiguous US and Alaska, Hawaii, and 10 world regions. TSAM also uses the FAA Aerospace Forecast projections of domestic and international cargo tonnage delivered to make a projection of cargo flights growth.

Projections for air transportation depend primarily on cost, duration and convenience compared to competing modes. Advances in technology that improve these factors stimulate demand. Future projections of economic growth, population growth and geographic distribution of population are the underlying drivers.

The model follows a four-step framework:

- **Trip Generation**: Prediction of the total number of trips
- **Trip Distribution**: Distribution of the trips generated amongst the origins and destinations
- **Mode Choice**: Prediction of the mode of travel individuals will choose for these trips
- **Network Analysis**: Prediction of the route the travelers will choose for their trip

Ticket price is a major factor that influences demand for commercial air travel. TSAM bases ticket prices on historical data from the Airline Origin and Destination Survey (DB1B) database. For some routes, historical data is not available so for those TSAM uses a fare model. TSAM estimates future fares by scaling baseline year fares. The scalar depends on a number of factors, but a significant component of ticket price is fuel cost. This analysis uses the 2014 FAA Aerospace Forecast and as an alternative, the Energy Information Administration (EIA) projections from the EIA Annual Energy Outlook 2014. Figure 2 shows the different fuel price forecasts and Figure 3 the corresponding TSAM airfare scale factors. The EAI projects higher fuel costs than the FAA and that results in higher ticket prices in future years.

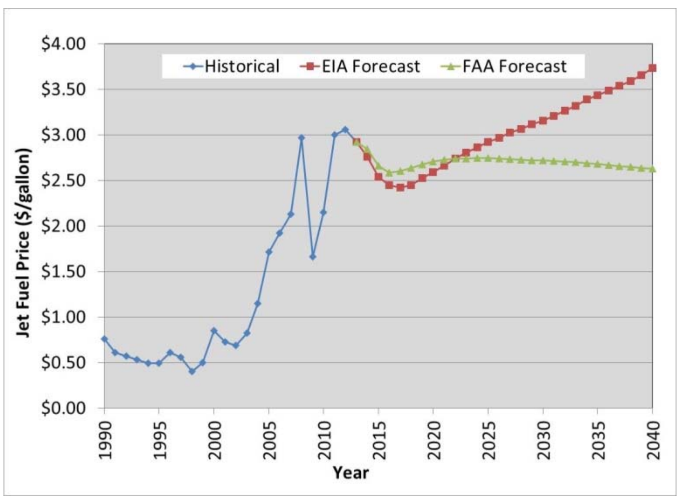

Figure 2. Jet Fuel Price Forecast

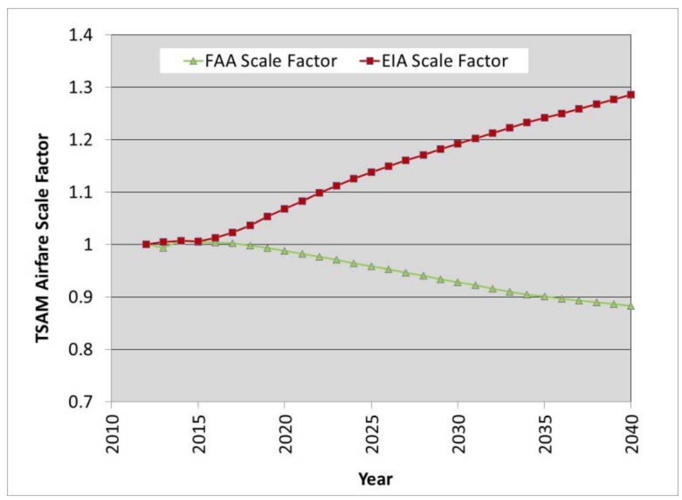

Figure 3. TSAM Future Airfare Scale Factor

TSAM allocates passengers to a mode and a route; the final step is to generate an airline schedule for ACES simulation. The methodology is to scale up a baseline day of traffic recorded by the FAA's Enhanced Traffic Management System (ETMS) using TSAM calculated growth factors for each route segment. TSAM utilizes an algorithm that both upgage aircraft, as well as increases flight frequency to accommodate route demand growth. A linear scaling of existing aircraft on the route can result in an unrealistically high frequency of flights on busy routes. In addition, there may be sufficient future demand to warrant introduction of commercial service between airports that currently do not have direct flights. The section Basis for the Introduction of Larger Aircraft and Direct Routes describes the process used to create these more realistic scenarios.

In addition to the commercial airline and cargo traffic projections from TSAM, General Aviation (GA) traffic contributes to the future traffic load in the NAS. NASA uses a "GA Operations Model" to predict GA demand based on an original code created by LMI. Instrument Flight Rules (IFR) GA traffic is included in the analysis to add to the overall demand. Most of this GA traffic is between smaller airports and is not the focus of this study.

Basis for the Introduction of Larger Aircraft and Direct Routes

Scaling up the baseline demand directly using TSAM growth factors leads to an unrealistic schedule for a few high traffic routes for the reasons explained in the section Transportation Systems Analysis Model. The schedule needs modifying, to consolidate passengers using multiple smaller aircraft into fewer larger aircraft and to introduce new direct routes when demand warrants.

Small Jet Consolidation

To model the airline trend of replacing uneconomical 30-50 passenger regional jets with larger 75-100 passenger jets, a small jet consolidation methodology is used. This methodology applies to CRJ1, CRJ2, DH8A, DH8C, E120, E135 and E145 aircraft types. If the total number of passengers on a flight segment exceeds 100 per day then CRJ9 aircraft with a capacity of 76 passengers and CRJ10 aircraft with a capacity of 100 passengers replace the smaller regional jets. The selected aircraft mix has the minimum number of flights with seating capacity greater than or equal to the original flights.

Schedule Frequency Growth Consolidation

Airlines tend to increase flight frequency on a route as demand increases but only to the point at which increased frequency does not gain any market share. When a route has sufficient frequency, introducing larger aircraft with lower per seat costs is a better option. Airbus developed a frequency/capacity split model based on their historical analysis of airline route data originally published in "Airbus Global Market Forecast, 2005 to 2024".

The frequency/capacity split has a minimum and maximum frequency for a route and varies with distance:

- If schedule frequency < minimum service frequency for segment distance then all growth accommodated by increased frequency
- If schedule frequency > maximum service frequency for segment distance then all growth accommodated by increased aircraft capacity
- If schedule frequency > minimum service frequency for segment distance and < maximum service frequency for segment distance then growth accommodated by combination of increased frequency and increased aircraft capacity

Consolidation of the future flight schedules uses a methodology based on this Airbus frequency/capacity split model. Figure 4 shows the limit on the number of daily flights as a function of future flight frequency for a range of baseline numbers of flights. The maximum number of daily flights used is; 40 for segments less than 1,000 nmi and 20 for routes longer than this. If the projected future schedule frequency exceeds the calculated limit then larger aircraft replace multiple smaller aircraft. The methodology does not remove baseline flights and does not consolidate aircraft that have more than 300 passenger capacity. There is a maximum of four flights consolidated into one larger aircraft. The methodology selects an appropriate mix of larger aircraft types to accommodate the number of passengers while meeting the schedule frequency limit.

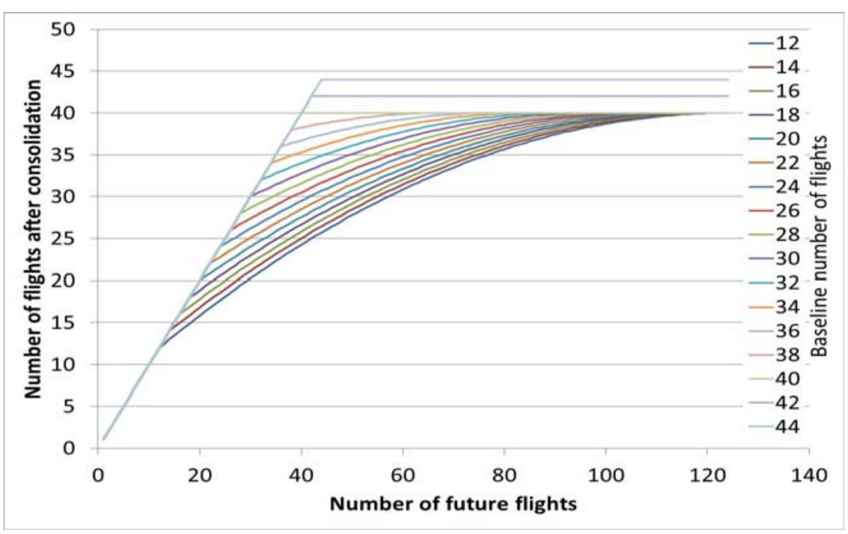

Figure 4. Consolidation of Multiple Smaller Aircraft Flights to a Reduced Number of Larger Aircraft Flights

Introduction of Direct Routes

As socio-economic and demographic factors change, demand increases for potential future service between some airports that do not currently have direct service. At some level of demand, it is likely that airlines will introduce a new direct route to service that demand. A direct-route introduction methodology models that effect. As the number of projected enplanements exceeds a threshold, the methodology introduces a minimum of two flights per day as morning-evening pairs. Increasing schedule coverage occurs as demand increases. The thresholds used currently are 40,000 enplanements per year for segments 1,500 nmi or less and 50,000 enplanements per year for longer routes. If the baseline demand already exceeds the threshold and there is no direct service, the methodology does not add a direct route. This limitation is arbitrary (and can be changed), but the assumption is that other factors have prevented the airlines from providing direct route service. The aircraft types used initially are CRJ9 and B737 respectively; these may be consolidated into larger aircraft as demand increases.

Influence of Increased Travel Times on Passenger Choice of Route and Mode

Travel time is a major factor that influences passenger choice of mode and route for a trip. Passengers may choose to travel by car, rather than aircraft for shorter trips if the time advantage of air travel is lost due to increased travel times. In some regions of the U.S. rail is a viable alternative. For longer trips where the only practical option is travel by aircraft, passengers may seek out alternative airline routes avoiding congested airports if the network allows.

Increased travel times can be a direct result of systemic delays on a route effecting passengers, or indirectly the airlines can add time or “padding” to the flight-segment time to take into account routine delays. Both result in some loss of demand because the time increase reduces the utility of the trip. These changes in travel time can be input into TSAM and the effects on the travelers’ choices of mode or route to make the trip can be modeled. Note that the overall number of trips does not change. TSAM does not estimate the number of trips not taken due to increased travel times.

Another major factor that influences passenger choice of mode is trip cost. It is likely that on congested routes, airlines would increase prices, to offset the cost of delays and to take advantage of the high demand; passengers are likely willing to pay more on popular routes. Raising ticket prices would increase the numbers of passengers switching modes or changing to an alternative air route. This effect on airfares is not included in the TSAM calculations, so there is a conservative estimate in the reduction of airline trips due to increased travel times.

Table 1 summarizes the effects of increased travel time observed from TSAM analysis for the year 2030-projected demand. The effects of schedule padding are more significant than congestion overall. Although the losses are small, a combined loss of 0.74% of round-trip passengers annually is loss of potential revenue to airlines, in addition to the direct costs caused by delays.

Table 1. Change in Round Trips due to Schedule Padding and Delays for 2030 Scenario

Scenario	Millions of Round Trips Annually			
	Rail	Airline	Auto	Total
1) Unimpeded Travel Times without Schedule Padding	12.02	302.67	1232.68	1547.37
2) Travel Times Based on OAG with Schedule Padding	12.10	301.11	1234.16	1547.37
3) Travel Times Based on OAG with Schedule Padding + Congestion Delays	12.13	300.45	1234.79	1547.37
Difference in Trips (2-1)	0.08 (0.67%)	-1.56 (-0.52%)	1.48 (0.12%)	0
Difference in Trips (3-2)	0.03 (0.25%)	-0.66 (-0.22%)	0.63 (0.05%)	0
Difference in Trips (3-1)	0.11 (0.92%)	-2.22 (-0.74%)	2.11 (0.17%)	0

Effect of Schedule Padding

TSAM uses airline schedule times from the Official Airlines Guide (OAG) for the air segment of the trip. However, the OAG times include padding to account for the expected routine delays on a route. Schedule padding is necessary to

maintain an on-time schedule. Passengers can then better plan their trips, avoid missed connections and airlines can report a greater percentage of on-time arrivals than would otherwise be the case. Airlines must balance these factors with the additional cost of schedule padding since crew cost increases and aircraft utilization decreases.

In addition, this increased trip time causes some loss in demand, especially on the shorter routes. Comparing the OAG schedule times with the unimpeded air-route segment times from ACES simulation gives an estimate of the amount of padding on each segment. The unimpeded times are calculated using trajectories actually flown, as recorded in the ETMS baseline data, so may not be the minimum time for optimal routing. However, this serves as an approximation. Comparing the TSAM projections for trip times with and without padding then gives an indication of the effect on passenger choice.

Table 1 shows a small reduction in annual airline round trips of 1.56 million, that is 0.52%. Of these, 1.48 million switch to auto and 0.08 million to rail.

Table 2 shows the reduction in the number of airline passengers on the top 10 flight segments with most percentage reduction due to schedule padding. All of these segments originate or terminate at New York City area airports, and the schedule padding is significant on most. Note that the passenger numbers do not include passengers on the domestic leg of an international trip which can be significant for both KJFK[1] and KEWR. Also note that two routes have less than 6 minutes of additional schedule time but still show significant reductions in passengers. The overall effect on passengers includes the effect of airport switching based on the relative times on other route choices and the network interactions are complex.

Table 3 shows how longer trip times effect domestic enplanements at the airports with the most change. The table does not include international and domestic leg of international-trip enplanements. Overall, KEWR loses 5.8% of total enplanements due to congestion and KATL 4.8%, with the other airports losing lesser amounts. Some airports actually gain passengers; this is surprising, given increased trip-times, but is likely due to passenger route choices changing because of the increased trip-times on alternative routes.

These results confirm that schedule padding can cause significant passenger losses on some routes compared to those achievable for predictable unimpeded times. Schedule padding can have a cost to the airlines due to additional to crew cost and loss of aircraft utilization, but padding is used to provide a reliable schedule for the airlines.

(For conciseness standard 4 letter airport identifiers are used in tables and text; the full airport names and locations are available e.g. from http://www.airnav.com/airport/)

Table 2. Reduction in Airline Passengers on Flight Segments due to Schedule Padding for 2030 Scenario

Departure Airport	Arrival Airport	2030 Scenario based on ACES Unimpeded Trip Times		2030 Scenario based on Current Day OAG Trip Times		Difference Between Scenarios	
		Mean Segment Flight Time (h)	Mean Daily Passengers	Mean Segment Flight Time (h)	Mean Daily Passengers	Mean Segment Flight Time Increase (h)	Mean Daily Passengers Reduction
KPHL	KJFK	0.88	155	1.02	115	0.13	40 (26%)
KBDL	KJFK	0.97	141	1.35	113	0.38	29 (20%)
KPVD	KEWR	1.04	129	1.27	103	0.22	26 (20%)
KJFK	KRIC	1.39	59	1.65	47	0.26	12 (20%)
KBWI	KJFK	1.05	226	1.17	183	0.12	43 (19%)
KEWR	KBDL	0.82	225	0.98	186	0.16	40 (18%)
KJFK	KORF	1.28	160	1.40	133	0.12	27 (17%)
KBDL	KEWR	0.96	207	1.05	172	0.09	35 (17%)
KEWR	KTYS	1.83	94	2.15	79	0.32	16 (17%)
KCLE	KJFK	1.56	134	1.58	112	0.02	22 (17%)

Table 3. Change in Airline Passenger Domestic Enplanements at Airports due to Schedule Padding for 2030 Scenario

Airport	2030 Scenario based on ACES Unimpeded Trip Times Daily Passenger Enplanements	2030 Scenario based on Current Day OAG Trip Times Daily Passenger Enplanements	Difference Between Scenarios
KEWR	34,633	32,628	-2,006 (-5.8%)
KATL	169,126	161,011	-8,115 (-4.8%)
KLGA	45,026	43,072	-1,955 (-4.3%)
KJFK	24,812	23,959	-853 (-3.4%)
KDTW	57,386	55,697	-1,689 (-2.9%)
KPHL	40,063	39,168	-895 (-2.2%)
KORD	119,465	117,022	-2,443 (-2.0%)
KSFO	50,232	49,444	-788 (-1.6%)
KMSP	65,516	64,594	-922 (-1.4%)
KBOS	39,957	39,424	-533 (-1.3%)
KDFW	105,185	107,479	2,294 (2.2%)
KDEN	124,627	126,273	1,647 (1.3%)
KBWI	29,655	29,938	283 (1.0%)
KLAS	62,459	62,949	491 (0.8%)
KSLC	51,821	52,054	233 (0.5%)
KPHX	73,586	73,903	317 (0.4%)
KSEA	50,411	50,592	181 (0.4%)
KMCO	33,023	33,046	23 (0.1%)

Effect of Congestion

The average delay from ACES for all of the flights on a route for a single day gives an estimate of the increased trip times. Using these increased trips times in TSAM to create a new demand forecast for 2030 results in a further reduction in annual airline round trips, Table 1, of 0.66 million, that is 0.22% compared to the OAG based trip times. This number is surprisingly small but is likely because OAG schedule padding is excessive for a good weather day. Currently most flights arrive early in good weather. Of these airline trips lost, 0.63 million switch to auto and 0.03 million to rail.

Table 4 shows the reduction in the number of domestic airline passengers on the top 10 flight segments with most percentage reduction due to congestion. The flight segments with fewer than 100 passengers generally have only a couple of flights per day so any reductions will not significantly change overall delays at the origin or destination airports. KJFK is the destination for all but one of the routes with the largest reductions in passengers; the remaining route originates at KJFK. Two high-traffic routes, KBOS to KJK and KDCA to KJFK lose almost half their demand.

Table 5 shows how longer trip times effect domestic enplanements at the airports with most change. The table does not include international and domestic legs of international-trip enplanements. Overall, KJFK loses 13.2% of total domestic enplanements due to congestion and KDCA 10.5%, with the other airports losing lesser amounts. Both KLGA and KEWR gain passengers, which is likely the result of passengers switching to other New York airports to avoid congestion at KJFK.

Table 4. Reduction in Domestic Airline Passengers on Flight Segments due to Congestion for 2030 Scenario

Departure Airport	Arrival Airport	2030 Scenario based on Current Day OAG Trip Times		2030 Scenario based on ACES Delayed Trip Times		Difference Between Scenarios	
		Mean Segment Flight Time (h)	Mean Daily Passengers	Mean Segment Flight Time (h)	Mean Daily Passengers	Mean Segment Flight Time Increase (h)	Mean Daily Passengers Reduction
KBDL	KJFK	1.35	113	5.03	29	3.68	84 (74%)
KELM	KJFK	0.88	38	5.89	11	5.01	27 (71%)
KGSO	KJFK	1.88	42	7.09	17	5.21	25 (60%)
KBWI	KJFK	1.17	183	3.93	78	2.76	104 (57%)
KMVY	KJFK	1.05	42	4.59	21	3.54	21 (50%)
KPHL	KJFK	1.02	115	2.71	59	1.69	56 (49%)
KJFK	KBDL	1.07	99	1.01	52	-0.06	46 (47%)
KACK	KJFK	0.98	29	3.38	16	2.40	13 (46%)
KBOS	KJFK	1.12	1308	3.30	722	2.18	586 (45%)
KDCA	KJFK	1.08	698	3.53	388	2.45	310 (44%)

Table 5. Change in Airline Passenger Domestic Enplanements at Airports due to Congestion for 2030 Scenario

Airport	2030 Scenario based on Current Day OAG Trip Times Daily Passenger Enplanements	2030 Scenario based on ACES Delayed Trip Times Daily Passenger Enplanements	Difference Between Scenarios
KJFK	23,959	20,802	-3,157 (-13.2%)
KDCA	37,532	33,596	-3,937 (-10.5%)
KBWI	29,938	29,142	-795 (-2.7%)
KDFW	107,479	105,739	-1,740 (-1.6%)
KPHX	73,903	72,956	-947 (-1.3%)
KLAS	62,949	62,266	-684 (-1.1%)
KSLC	52,054	51,545	-509 (-1.0%)
KDEN	126,273	125,485	-789 (-0.6%)
KSEA	50,592	50,375	-217 (-0.4%)
KMDW	42,169	41,990	-180 (-0.4%)
KEWR	32,628	34,238	1,611 (4.9%)
KLGA	43,072	44,755	1,684 (3.9%)
KATL	161,011	166,899	5,888 (3.7%)
KORD	117,022	120,859	3,837 (3.3%)
KPHL	39,168	40,406	1,238 (3.2%)
KDTW	55,697	57,342	1,645 (3.0%)
KLAX	67,587	68,644	1,057 (1.6%)
KCLT	64,270	64,978	708 (1.1%)
KSFO	49,444	49,982	538 (1.1%)
KMSP	64,594	65,035	440 (0.7%)

Even though the overall system-wide reductions in airline trips are small, airports with severe congestion show significant reductions in trips and consequently delays on some routes as discussed in results section Effect of Passenger Choice on Congestion.

Description of Data Sets Used for Analysis

ACES simulation requires a Flight Data Set (FDS) containing a departure schedule and flight plan for all the IFR flights in the NAS for the scenario of interest. This analysis uses a baseline scenario, representative of current operations

and three scenarios for the year 2030. The baseline scenario, recorded on 25 July 2012 is representative of NAS operations on a high volume good weather day.

The 2030 scenarios use TSAM demand projections with two different fuel price forecasts. The fuel price forecasts are the FAA's estimated fuel price and the EIA forecast. The EIA forecasts higher fuel prices than the FAA and this reduces demand for air transportation. In addition, a variation of the 2030 scenario using FAA's fuel price forecast uses ACES derived delays to influence the commercial airline schedule as described in Influence of Increased Travel Times on Passenger Choice .

The Full FDS file contains 42 hours of traffic: 12 hours of "pre traffic" plus 24 hours of "Traffic of Interest" plus 6 hours of "post traffic". The Traffic of Interest consists of a day of traffic that is the basis for the analysis in this paper. The pre traffic ensures a fully populated NAS airspace to initialize all ACES NAS system models before the Traffic of Interest segment starts in the simulation. The post traffic maintains a fully populated NAS airspace to allow the Traffic of Interest to end with all ACES NAS system models fully loaded. This is particularly important to ensure correct functioning of the Traffic Flow Management (TFM) models in ACES. If the simulation is not fully loaded with traffic then TFM applies less delay to flights, so any analysis of delays will under-predict the effects of congestion.

Table 6 lists a summary of the FDS scenario data and shows the number of flights in each category for the 24 hours of interest. The total traffic growth from TSAM projections is 37% over 2012 levels by the year 2030 using the FAA's fuel price data.

The difference between the 2030 FAA forecast and the 2030 EIA fuel price forecast only applies to domestic passenger airfares. The EIA higher fuel price results in 5.6% less growth in domestic passenger flights. The corresponding total growth is 34% over 2012 levels including all traffic.

When frequent delays add to perceived trip-times, some passengers choose to travel by auto or select an alternative less delayed flight route. This only effects Domestic Passenger flights and results in 0.6% fewer flights overall. (Note that domestic legs of international trip passengers are included in the flight data sets but are not affected by the delay methodology used for this analysis.)

Table 6. Characteristics of Flight Data Sets used For Analysis

Scenario	Domestic Cargo	International Cargo	General Aviation	Domestic Passenger	International Passenger	Total
2012 Baseline	1296	324	19059	20599	3859	45132
2030 FAA Forecast	1683	753	23276	28013	7998	61723
Increase Over Baseline (%)	29.9%	132.4%	22.1%	36.0%	107.3%	36.8%
2030 FAA Forecast with Delay Influence on Passenger Choice	1683	753	23276	27884	7998	61594
Increase Over Baseline (%)	29.9%	132.4%	22.1%	35.4%	107.3%	36.5%
2030 EIA Forecast	1683	753	23276	26865	7998	60575
Increase Over Baseline (%)	29.9%	132.4%	22.1%	30.4%	107.3%	34.2%

Airspace Simulation

This study uses NASA's ACES Version 8.5. ACES is a fast time, distributed, agent-based simulation of the National Airspace System (NAS). ACES has models of airports, airspace, aircraft performance, basic Traffic Flow Management (TFM) and other elements of the NAS. The primary input is a flight schedule simulating a day of NAS operations. Outputs can include measures of airspace loading, airport loading, and numbers of conflicts requiring avoidance maneuvers, delays, throughput, fuel-burn and distance flown amongst other metrics. For this analysis, the primary metric of interest is delay, allocated to the various sources determined by simulation. ACES determines delay at various stages of flight by comparing the trajectory flown in simulation with a computed unimpeded trajectory. Total delay for each flight is the difference between actual gate arrival time in the simulation and the calculated unimpeded gate arrival time.

ACES models the airport and airspace capacity constraints of the NAS. There are several choices of airport model available with different levels of fidelity. The basic airport model used for this analysis represents each airport as a node in the network with constraints on departure, arrival and total operations per hour. Airspace sectors are 3-

dimensional regions in space with an associated maximum number of aircraft that can occupy the region simultaneously.

The basic TFM in ACES predicts demand for resources and attempts to reduce traffic flow to ensure airports and airspace sectors are not overloaded. This results in delay to individual flights, either on the ground or in the air. The basic TFM model favors ground delays and then performs delay maneuvers in-flight, if needed. It does not perform rerouting around congested airspace.

Basis for Current Day and Future Airport Capacity Estimates

The ACES basic airport model requires a data file that specifies the maximum departure operations, maximum arrival operations and maximum combined operations for various weather conditions. The airport capacity file supplied with ACES "Top250AirportCapacity" contains data for the largest 250 airports, plus default values for the smaller airports. This file represents the estimated current airport capacities, last updated in 2010.

The FAA has a "Future Airport Capacity Task" (FACT) team that analyses future capacity needs to determine which airports are likely to be constrained in the future, based on best estimates of future capacity. NASA obtained some pre-release FACT3 data from the FAA to insure the latest available projections of capacity were used in the current constraints analysis. FACT3 has capacity data for 69 airports for year 2011 (baseline), and improvements for 2020 and 2030 with various assumptions. Runway improvements at KFLL, KORD and KPHL are included for 2020 with additional improvements for KPHL in 2030. Different levels of Air Traffic Control (ATC) improvements are also included, based on current NextGen planning and additional proposed improvements. In FACT3, these levels are "Near Term" NextGen, "Mid-Term" NextGen and "Advanced ATC".

Of the 69 FACT3 airports, 63 are currently in the ACES TOP250AirportCapacity file and 6 are additional (KDVT, KGYY, KHND, KHNL, KIWA, KTMB). NASA merged the FAA 69 airports data with the existing ACES 250 airport data to create the files:

- 2011_Base_NASA_FACT3_256_AirportCapacity
- 2030_AdvATC_NASA_FACT3_256_AirportCapacity

The 2030 file with "Advanced ATC" assumptions represents Operational Improvements that are part of FAA's NextGen plans and concepts. There are additional improvements that NASA and other researchers are investigating that are not included.

This analysis uses NASA's post-processing of the FAA's 2030 data. Note that the ACES data files only include 3 capacity data points whereas the FAA data has multiple points representing a capacity Pareto boundary. The capacity values used for ACES are a simplification of the FAA supplied data and are not exactly the FAA supplied values.

Notes: The latest FACT 3 report is now available, published January 2015, reference 1. The final airport capacity values differ slightly from the pre-release data but are broadly similar. The "Advanced ATC" airport capacity values are not included in the published FACT3 report, since the report only contains projections for the year 2020.

Table 7 lists the assumed capacities and the differences compared to 2011 baseline values for the top 35 of the 256 airports modeled by ACES. Note that some airports show a small decrease in capacity from 2011 to 2030. This is due to a change in the traffic weight category mix assumed by the FAA for the FACT3 analysis. The most significant increases are due to additional or improved runways.

Table 7. VMC Airport Capacities used by ACES Simulation

OEP 35 Airports		2011			2030 AdvATC			Dep Diff	Arr Diff	Tot Diff	Dep %Diff	Arr %Diff	Tot %Diff
		Dep	Arr	Tot	Dep	Arr	Tot						
KATL	Hartsfield-Jackson Atlanta	140	120	221	167	130	255	27	10	34	19%	8%	15%
KBOS	Boston Logan	77	67	128	82	73	133	5	6	5	6%	9%	4%
KBWI	Baltimore/Washington	54	46	67	61	52	69	7	6	2	13%	13%	3%
KCLE	Cleveland Hopkins	97	83	132	99	91	134	2	8	2	2%	10%	2%
KCLT	Charlotte Douglas	102	130	181	119	139	194	17	9	13	17%	7%	7%
KCVG	Cincinnati/Northern Kentucky	126	129	183	131	142	190	5	13	7	4%	10%	4%
KDCA	Reagan Washington National	55	51	70	55	52	67	0	1	-3	0%	2%	-4%
KDEN	Denver	209	179	297	236	193	331	27	14	34	13%	8%	11%
KDFW	Dallas/Fort Worth	107	172	262	112	193	287	5	21	25	5%	12%	10%
KDTW	Detroit Metropolitan Wayne	96	133	189	109	145	206	13	12	17	14%	9%	9%
KEWR	Newark Liberty	71	49	111	67	64	110	-4	15	-1	-6%	31%	-1%
KFLL	Fort Lauderdale/Hollywood	66	55	81	75	87	124	9	32	43	14%	58%	53%
KHNL	Honolulu	113	74	122	126	69	126	13	-5	4	12%	-7%	3%
KIAD	Washington Dulles	106	121	129	113	119	187	7	-2	58	7%	-2%	45%
KIAH	George Bush Houston	103	94	197	117	101	217	14	7	20	14%	7%	10%
KJFK	New York John F. Kennedy	61	77	94	71	87	107	10	10	13	16%	13%	14%
KLAS	Las Vegas McCarran	59	82	122	58	92	132	-1	10	10	-2%	12%	8%
KLAX	Los Angeles	95	86	165	112	93	181	17	7	16	18%	8%	10%
KLGA	New York LaGuardia	47	44	83	54	49	90	7	5	7	15%	11%	8%
KMCO	Orlando	101	85	172	109	129	189	8	44	17	8%	52%	10%
KMDW	Chicago Midway	95	40	97	99	41	100	4	1	3	4%	3%	3%
KMEM	Memphis	101	107	149	118	132	154	17	25	5	17%	23%	3%
KMIA	Miami	92	77	155	110	118	174	18	41	19	20%	53%	12%
KMSP	Minneapolis/St. Paul	117	123	168	120	134	172	3	11	4	3%	9%	2%
KORD	Chicago O`Hare	116	125	235	217	191	329	101	66	94	87%	53%	40%
KPDX	Portland	66	78	124	66	86	125	0	8	1	0%	10%	1%
KPHL	Philadelphia	105	60	137	130	90	208	25	30	71	24%	50%	52%
KPHX	Phoenix Sky Harbor	68	83	150	85	92	163	17	9	13	25%	11%	9%
KPIT	Pittsburgh	109	83	162	110	83	163	1	0	1	1%	0%	1%
KSAN	San Diego	44	42	57	51	46	60	7	4	3	16%	10%	5%
KSEA	Seattle/Tacoma	68	60	116	72	65	121	4	5	5	6%	8%	4%
KSFO	San Francisco	101	71	111	101	74	105	0	3	-6	0%	4%	-5%
KSLC	Salt Lake City	124	98	158	123	102	160	-1	4	2	-1%	4%	1%
KSTL	Lambert Saint Louis	107	80	131	104	82	128	-3	2	-3	-3%	3%	-2%
KTPA	Tampa	72	75	116	72	77	117	0	2	1	0%	3%	1%

Basis for Current Day and Future Sector Capacity Estimates

The ACES airspace sector model requires latitude, longitude and altitude boundary data, plus a capacity value for all included sectors. The current day baseline data is from FAA data for year 2012 sectors.

It is likely that increased automation along with advanced ATC tools will improve airspace capacity by 2030. It is possible that the existing sector based architecture will no longer be required. For this study, the future sector capacities are not a primary focus. The simulation used a 20% and 50% NAS-wide increase in sector capacities and unconstrained sector capacities (i.e. no limits on number of aircraft occupying a sector) to enable an analysis of delay sensitivity to airspace capacity.

Results and Discussion

Results from simulation using ACES indicate where major delays arise due to an excess of demand over capacity at constrained resources.

Analysis of ACES delay data can quantify the delay at the point taken and quantify the delay according to the source. For example, for 100 hours of total departure delay taken at the gates of airport “X”: the source of delay is 50 hours due to insufficient departure capacity at “X”; 25 hours due to insufficient arrival capacity at airport “Y”; and the remaining 25 hours due to airspace congestion at various identified sectors.

The analysis of sectors congestion is particularly complex since there are many interactions with other sectors and with airports that can influence the load on a specific sector. The aggregate amount of system-wide sector delay is a good indication of airspace congestion and the number and geographic locations of overloaded sectors can give insight into the worst airspace choke points.

Table 8 shows the potential causes of delay identified by ACES:

- Delays from Causes 1 and 2 are allocated to the subject airport “X”
- Delays from Cause 3 are allocated to “X” as source but taken at “Y”
- Delays from Causes 4 and 5 are allocated to “X” as source but taken in-flight
- Delays from Cause 6 are taken at “X” but allocated to sector congestion
- Delays from Causes 7 and 8 are allocated to sector congestion and taken in-flight

Table 8. Causes of Delay Identified by ACES Simulation

Cause #	ACES Identifier	Explanation
1	ATC_AAR	Landing delay to meet Airport Arrival Rate (insufficient arrival capacity at “X”)
2	ATC_ADR	Takeoff delay to meet Airport Departure Rate (insufficient departure capacity at “X”)
3	TFM_AAR_GATE	Gate departure delay (at “Y”) due to capacity restrictions at destination airport (insufficient arrival capacity at “X”)
4	TFM_AAR_MAN	Maneuvering delay (in-flight) due to capacity restrictions at airport (insufficient arrival capacity at “X”)
5	TFM_AAR_INT	International crossing delay (in-flight) due to capacity restrictions at airport (insufficient arrival capacity at “X”)
6	SECTOR_CONGESTION_GATE	Gate departure delay (at “X”) due to congestion in sector
7	SECTOR_CONGESTION_MAN	Maneuvering delay (in-flight) due to congestion in sector
8	SECTOR_CONGESTION_INT	International crossing delay (in-flight) due to congestion in sector

Summary of Results

Table 9 shows a summary of the results obtained from ACES simulation. Detailed analysis follows in later sections. Note that the total “Flights in 24 h” in the table is slightly less than in the “Total” in Table 6. This is because ACES rejects a small number of flights due to non-flyable trajectories or unknown aircraft types etc.

For the Year 2012 scenario (run 1) with current day airports and airspace capacities, delays are generally low system-wide on aggregate as expected since all simulation runs assumed perfect weather. Some airports are starting to become congested. Delay due to airspace congestion is negligible.

The Year 2030 scenarios using FAA’s fuel price forecast (runs 2 to 6) have 37% more flights in total than the 2012 scenario. The EIA forecasts somewhat higher jet fuel prices, leading to increased ticket cost and slightly less demand; run 7 has 34% more flights than the 2012 scenario. Note however that the total of all flights includes GA and cargo. The percentage increase in scheduled airline domestic plus international flights is 47% for the FAA’s fuel price scenario and 43% for the EIA fuel price scenario, see Table 6. The increase in scheduled airline flights is more relevant than the increase in total flights for the major airports.

Run 2 is using 2030 demand, but assuming no improvements in airports or airspace capacity. This is an unlikely worse case, but is useful for comparison. Aggregate delays are still not large, at 349 seconds per flight on average. However,

run 2 has 9 times the total delay of the 2012 scenario and that is for Visual Meteorological Conditions (VMC) capacities. In poor weather, there could be very long delays. Aggregate delays only give a broad overview of the state of the system; detailed analysis later in the report shows severe congestion at some airports and regions of airspace.

Runs 3 to 6 assume 2030 improvements to airports infrastructure and use of advanced ATC as described in Basis for Current Day and Future Airport Capacity Estimates. It is likely that increased automation along with advanced ATC tools will improve airspace capacity by 2030. It is possible that the existing sector based architecture will no longer be required. This study does not investigate expected increases in airspace capacity due to advanced technology and concepts; instead, the analysis determines delay sensitivity to sector capacities. The results show that increasing sector capacity by 20% reduces sector delay to the point that the dominant source of delay is insufficient airports capacity. Increasing sector capacity by 50% over current capacities reduces sector delays to negligible values. Furthermore, detailed analysis discussed later shows that only a small proportion of sectors are overloaded.

Run 7 using the EIA fuel price forecast shows a 12% reduction in total delay compared to run 3, for a 2% reduction in the number of flights. This indicates that a small reduction in flights can have a disproportionate effect on reducing delays. Once a resource starts to become overloaded, delays tend to increase very rapidly. This result is an indication that changes to the routing or scheduling of flights to avoid congested resources or peak times can be very beneficial to the NAS.

Run 8 with the influence of delays on passenger choice shows a 20% reduction in delays compared to run 6, for a 0.2% reduction in the total number of flights; that is due to a 0.6% reduction in airline domestic passenger flights. The disproportionate reduction in delay indicates that delays are highly sensitive to passenger choice. The delay reduction has two causes; passengers switching to an alternative mode; and switching to less congested flight routes. The aggregate change in flights does not give insight into the reasons for the reduction in delays. Detailed analysis later in this report shows that passengers avoiding the most congested routes have a disproportionate effect on delays.

Table 9. Summary of Delay Results

Run	Scenario/ Year	Airports Capacity	Airspace Capacity	Flights in 24 h	Airports Delay (h)	Sectors Delay (h)	Total Delay (h)	Mean Delay per
1	2012 (7/25/2012)	Current	Current Sectors	44598	623	33	656	53
2	2030	Current	Current Sectors	61039	4190	1739	5929	349
3	2030	2030 With Advanced ATC	Current Sectors	61039	2049	1608	3657	216
4	2030	2030 With Advanced ATC	Current Sectors + 20%	61039	2154	266	2420	143
5	2030	2030 With Advanced ATC	Current Sectors + 50%	61039	2166	14	2180	129
6	2030	2030 With Advanced ATC	Unconstrained	61039	2167	0	2167	127
7	2030 EIA Fuel Price Forecast	2030 With Advanced ATC	Current Sectors	59892	1716	1506	3222	193
8	2030 Passengers Influenced by Delays	2030 With Advanced ATC	Unconstrained	60908	1744	0	1744	103

Baseline Scenario for Year 2012

The baseline scenario, recorded on 25 July 2012 is representative of NAS operations on a high volume good weather day. The report section Description of Data Sets Used for Analysis describes the process for creation of the scenarios. The Basis for Current Day and Future Airport Capacity Estimates and Basis for Current Day and Future Sector Capacity Estimates list the corresponding capacity estimates.

Airports Congestion

The results discussed below are for run 1, Table 9.

Figure 5 shows that delays remain low throughout the 24 hours of simulated operations. The average total delay for the 2012 scenario is less than one minute per flight and there are no flights with more than 1 hour of delay. This indicates that for a simulated perfect weather scenario using current day airports and sector capacities, sufficient capacity exists to meet demand, on aggregate.

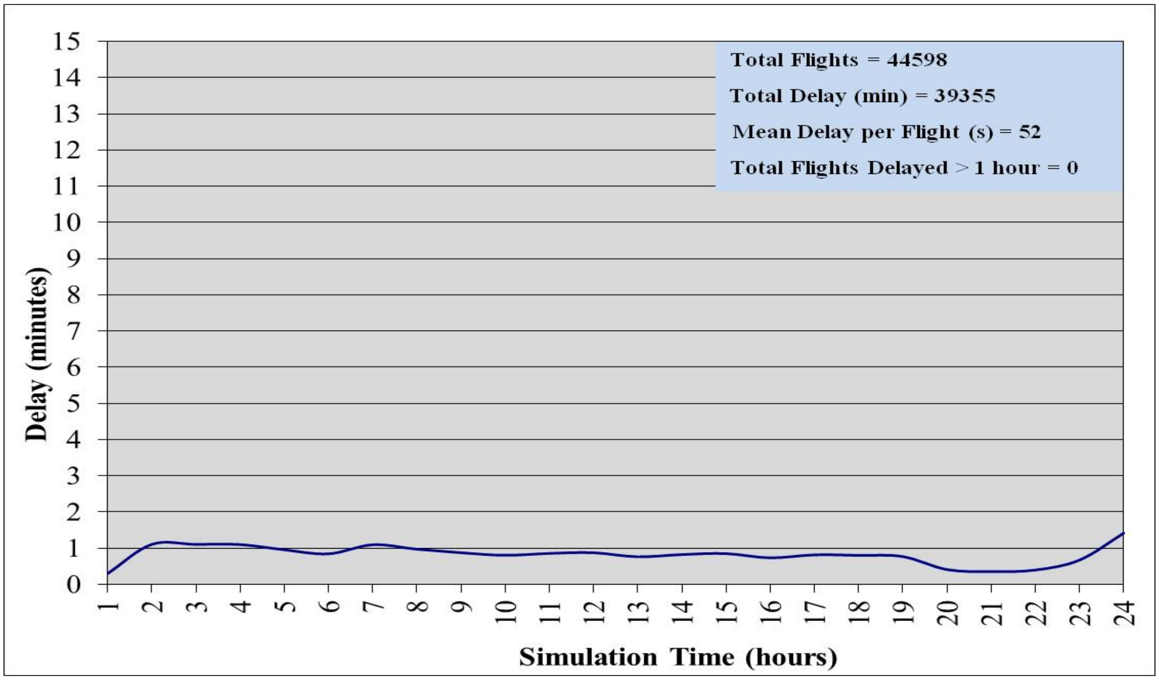

Figure 5. System-Wide Mean Hourly Delay per Flight for 2012 Scenario

Table 10 shows that delays at the 10 airports with most delay are low for this perfect weather scenario. The table shows the delay at the point taken, not allocated to the root cause.

Table 10. Airport Delay for 2012 Scenario

Airport	Total Delay (h)	Total Operations	Mean Delay per Operation (s)
KATL	59.2	2495	85
KLGA	49.1	1065	166
KPHX	36.2	1196	108
KCLT	34.5	1351	91
KJFK	33.4	1071	112
KDCA	26.4	773	123
KORD	23.8	2150	39
KEWR	19.6	1082	65
KMSP	19.1	1256	54
KLAX	18.3	1580	41

The airports with most delay are KATL and KLGA; delays are still low, since hourly demand is within Visual Metrological Conditions capacity as shown in Figure 6 and Figure 7. The figures show unconstrained demand, along with the actual departure plus arrival operations per hour. The actual operations are those that were achieved after any delays imposed by traffic flow management actions to meet capacity shortfalls. In both cases, the actual achieved operations are close to the unconstrained demand as expected, since there is sufficient good weather capacity at all times. The peak demand at KLGA almost reaches capacity for short periods, but there is still sufficient spare capacity between peaks to maintain low delays in VMC. In IMC when KLGA capacity reduces to 67 operations per hour, long delays are likely to occur since demand will then be above or near IMC capacity for extended periods.

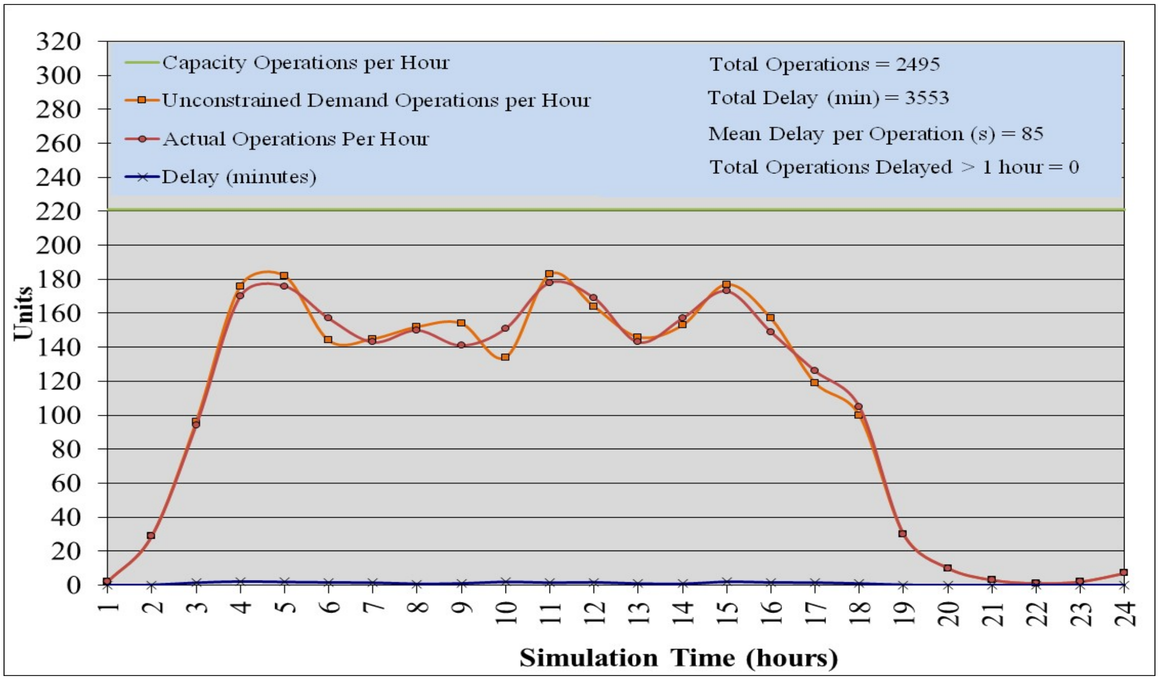

Figure 6. KATL Operations and Mean Hourly Delay per Operation for 2012 Scenario

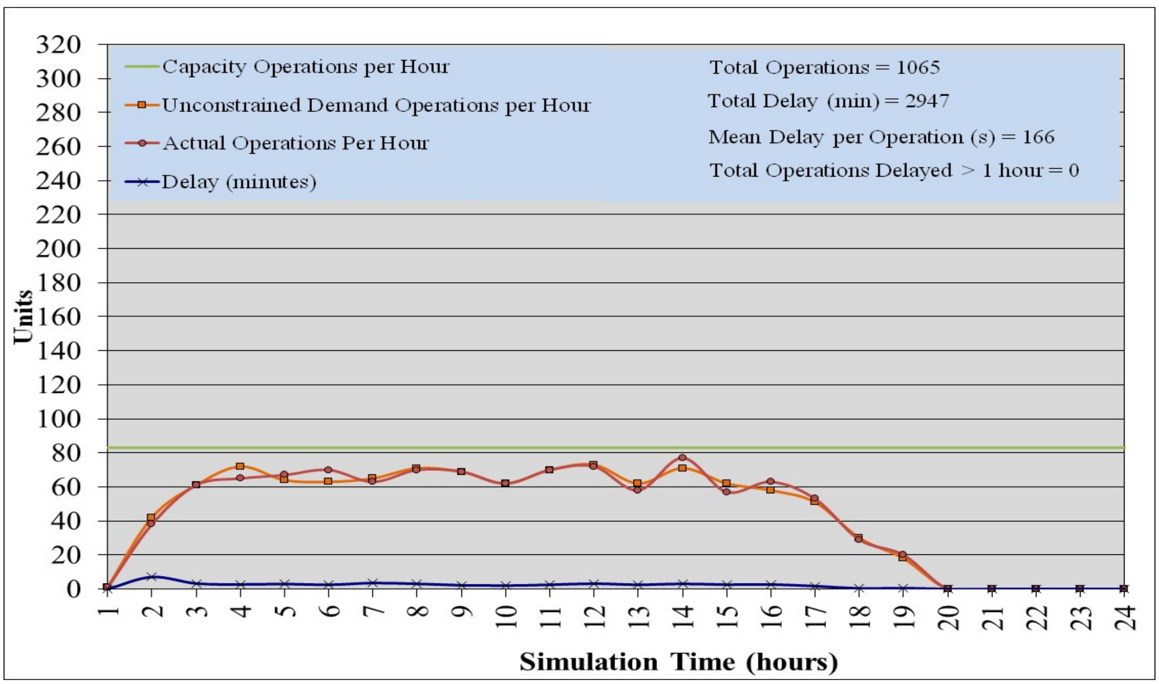

Figure 7. KLGA Operations and Mean Hourly Delay per Operation for 2012 Scenario

Table 11 shows delays allocated by cause as explained previously and defined in Table 8. Inadequate arrival or departure capacity at the subject airport causes most of the delay. This delays both the subject airports own operations (ATC_AAR+ATC_ADR) and other airports operations (TFM_AAR_GATE) plus some in-flight delay (TFM_AAR_MAN+TFM_AAR_INT). The subject airport is the root cause of all of this delay. For example, KATL is the cause of 62.5 hours of total delay. Note that from Table 10, 59.2 hours of this delay is actually taken at KATL, the rest is taken on the ground at other airports or in flight, but a capacity shortfall at KATL is the root cause. In addition, there is some delay caused by sector congestion, taken on the ground at the subject airport, but not caused by the subject airport.

For KORD, KEWR and KMSP the total delay caused by the airport is actually less than the delay taken at the airport. The additional gate delays are due to capacity restrictions at other airports.

Ranking by allocation of delay to root cause rather than by allocation by effect shows mainly the same airports causing most delay. However, the order is changed and KLAX drops from the top 10, replaced by KBWI. The two most delayed airports remain KATL followed by KLGA. Overall delays are low for this scenario.

Table 11. Allocation of Airport Delay by Cause for 2012 Scenario

Airport	ATC_AAR (h)	ATC_ADR (h)	TFM_AAR_ GATE (h)	TFM_AAR_ MAN (h)	TFM_AAR_ INT (h)	Total Airport Source Delay (h)	SECTOR_ CONGST_ GATE (h)	Total Delay (h)
KATL	15.7	37.4	5.7	3.8	0.0	62.5	0.4	63.0
KLGA	12.7	32.5	7.8	1.6	0.5	55.1	0.3	55.4
KPHX	4.7	30.4	0.7	0.3	0.0	36.1	0.5	36.6
KJFK	5.7	25.2	0.9	1.2	0.1	33.2	0.7	33.9
KCLT	5.2	27.5	0.7	0.4	0.0	33.7	0.1	33.9
KDCA	6.4	15.8	5.1	1.7	0.4	29.3	0.1	29.4
KORD	5.1	16.7	0.0	0.0	0.0	21.8	0.6	22.4
KBWI	4.4	11.6	4.5	0.7	0.1	21.3	0.2	21.5
KEWR	6.2	10.7	0.9	1.2	0.1	19.2	0.3	19.4
KMSP	3.0	13.1	0.1	0.0	0.0	16.3	2.7	18.9

Sectors Congestion

The total sector delay listed in Table 9 for run 1, is only 33 hours system-wide; this represents 5% of the total delay. This is for perfect weather. Table 8 defines the causes of delay reported by ACES. To prevent sector overload, TFM delays traffic on the ground (GATE) or in-flight (MAN+INT). Table 12 shows that delays at the 10 sectors with most congestion are low. There is some indication that Denver sector ZDV07 is congested, but with a more sophisticated TFM model than the basic ACES model rerouting some flights around ZDV07 could reduce gate-holds.

Table 12. Allocation of Sector Delay by Cause for 2012 Scenario

Sector	SECTOR_CONGST_GATE (h)	SECTOR_CONGST_MAN (h)	SECTOR_CONGST_INT (h)	Total Delay (h)
ZDV07	4.1	0.0	0.0	4.1
ZBW20	2.7	0.5	0.3	3.5
ZMP11	2.2	1.0	0.0	3.2
ZID76	1.6	0.3	0.2	2.0
ZLA39	1.2	0.8	0.0	2.0
ZLC41	0.8	0.6	0.1	1.5
ZMP17	1.2	0.3	0.0	1.5
ZNY55	1.2	0.2	0.0	1.4
ZMP20	0.9	0.4	0.0	1.3
ZAU33	0.3	0.8	0.0	1.0

Future Demand Scenario for Year 2030

TSAM projects Year 2030 demand for air transportation as described in Transportation Systems Analysis Model. The FAA's fuel price forecast and the EIA forecasts create two different levels of demand for analysis.

For ACES simulation two airport capacity sets are used; a current day set for comparison and a set representing the estimated capacities for 2030 assuming infrastructure improvements and advanced Air Traffic Control technology as described in Basis for Current Day and Future Airport Capacity Estimates.

The sector capacities used are current day plus 20% increase, 50% increase and unconstrained as described in Basis for Current Day and Future Sector Capacity Estimates.

The results below are for runs 2 to 8, Table 9. Run 7 is the only run using the EIA fuel price forecast scenario. Run 8 takes into account the influence of delays on passenger choice.

Airports Congestion

With Current Airport and Airspace Sector Capacities

Figure 8 shows aggregate delays for the 2030 demand scenario run 2, with current airport and airspace sector capacities. Using current capacities is not a realistic expectation of the available capacity in 2030; rather it allows analysis of the causes of delay, identifying shortfalls in capacity. Delays are substantially higher than for the baseline scenario, Figure 5 as expected since the number of flights has increased by 37% with no increase in capacity.

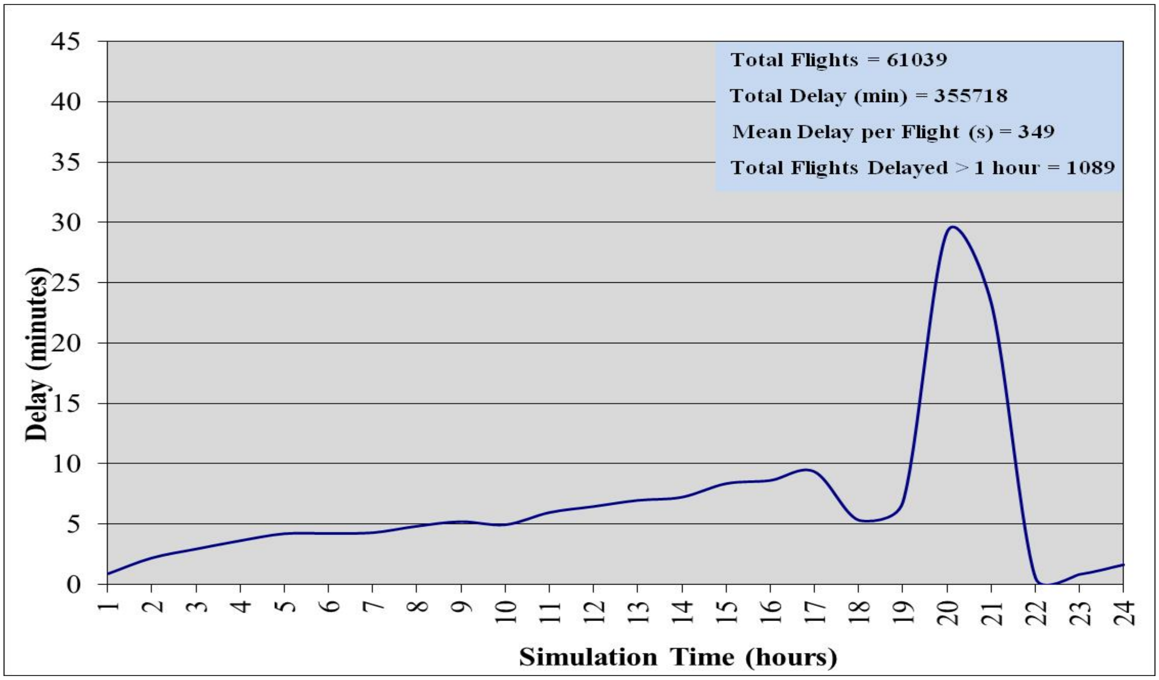

Figure 8. System-Wide Mean Hourly Delay per Flight for 2030 Scenario with Current Airport and Sector Capacities

Table 13 shows substantial delays at the 10 airports with most delay. The table shows the delay at the point taken, not allocated to the root cause.

Table 13. Airport Delay for 2030 Scenario with Current Airport and Sector Capacities

Airport	Total Delay (h)	Total Operations	Mean Delay per Operation (s)
KJFK	964.8	1768	1964
KMIA	396.7	1976	722
KATL	369.6	3422	388
KBOS	211.8	1407	541
KEWR	204.4	1682	437
KLGA	179.1	1334	483
KORD	176.7	2928	217
KCLT	175.7	1938	326
KDCA	165.2	1092	544
KFLL	147.5	927	572

Table 14 shows delays allocated by cause. The top choke point airport is KJFK followed by KATL, KLGA and KEWR. The analysis shows that a capacity shortfall at KJFK is responsible for 1506 hours of delay system-wide, although

operations at KJFK experience only 965 hours of this delay. The top 10 constrained airports account for 3564 hours of the 4190 hours of total delay listed in Table 9; that is 85% of the total delay due to airports.

Table 14. Allocation of Airport Delay by Cause for 2030 Scenario with Current Airport and Sector Capacities

Airport	ATC_AAR (h)	ATC_ADR (h)	TFM_AAR_ GATE (h)	TFM_AAR_ MAN (h)	TFM_AAR_ INT (h)	Total Airport Source Delay (h)	SECTOR_ CONGST_ GATE (h)	Total Delay (h)
KJFK	256.1	429.6	687.1	88.3	45.1	1506.2	105.0	1611.2
KATL	61.4	124.2	505.9	53.6	6.8	752.0	37.1	789.2
KLGA	37.3	73.9	369.5	20.3	18.4	519.5	6.2	525.8
KEWR	39.1	29.9	193.1	38.2	16.2	316.5	44.6	361.1
KMIA	14.1	15.3	2.8	1.8	4.3	38.3	273.9	312.1
KDCA	19.7	39.4	106.1	9.9	3.4	178.4	6.0	184.4
KPHX	9.4	66.8	5.7	2.2	0.5	84.6	21.6	106.3
KCLT	8.7	40.8	8.2	0.9	0.0	58.7	41.1	99.8
KFLL	5.4	9.3	1.4	2.2	0.8	19.0	80.0	99.1
KBWI	15.1	25.9	44.1	5.3	0.4	90.8	7.8	98.5

With 2030 Advanced ATC Airport and Unconstrained Airspace Capacities

Figure 9 shows aggregate delays for the 2030 demand scenario run 6, with 2030 Advanced ATC airport and unconstrained airspace capacities. In reality, airspace capacity is always limited; for the purposes of this section of the analysis, using unconstrained airspace allows analysis of airports constraints in isolation of airspace congestion effects. Delays are higher than for the baseline shown in Figure 5, indicating that even with all planned infrastructure improvements in place and assuming advanced ATC technologies, airport capacity is still not adequate to meet demand in 2030.

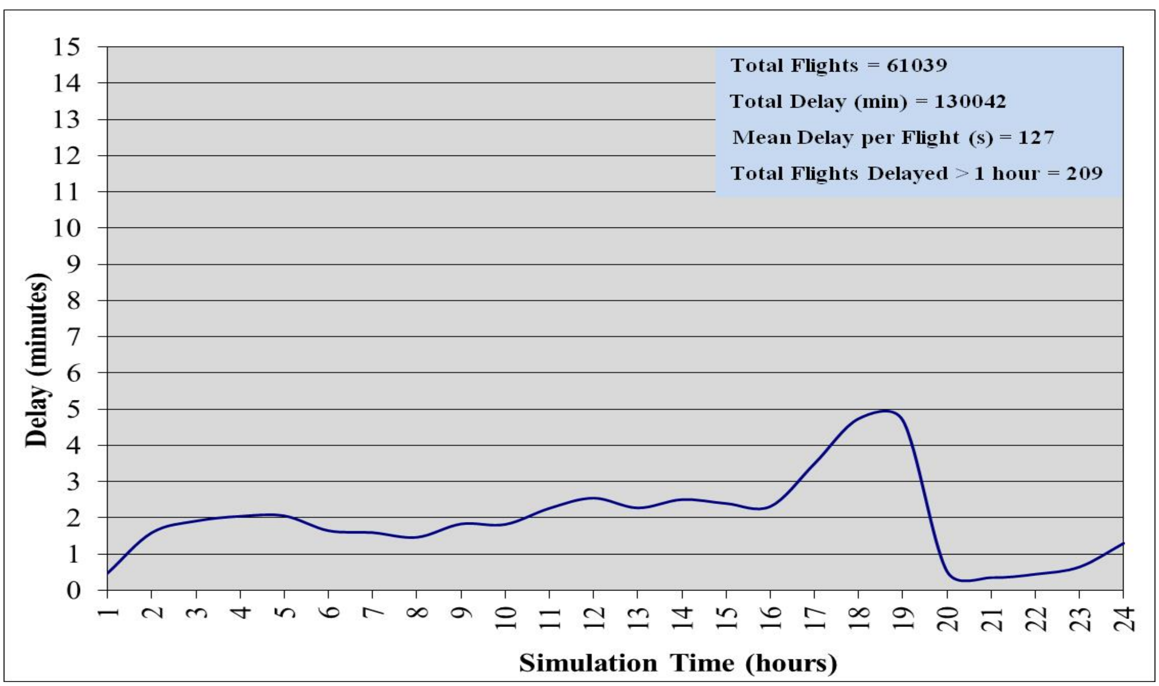

Figure 9. System-Wide Mean Hourly Delay per Flight for 2030 Scenario with 2030 Advanced ATC Airport and Unconstrained Airspace Capacities.

Table 15 lists the 10 airports with most delay. The table shows the delay at the point taken, not allocated to the root cause.

Table 15. Airport Delays for 2030 Scenario with 2030 Advanced ATC Airport and Unconstrained Airspace Capacities

Airport	Total Delay (h)	Total Operations	Mean Delay per Operation (s)
KJFK	404.3	1768	823
KATL	137.7	3422	144
KDCA	131.9	1092	434
KEWR	100.2	1682	214
KLGA	96.2	1334	259
KBOS	84.8	1407	216
KORD	61.7	2928	75
KBWI	57.9	1032	202
KCLT	53.2	1938	98
KSFO	44.7	1537	104

Table 16 shows airport delays allocated by cause without the influence of sector constraints. The top choke point airport is still KJFK, followed by KDCA. The analysis shows that a capacity shortfall at KJFK is responsible for 754 hours of delay system-wide, although operations at KJFK experience only 404 hours of this delay, Table 15. The top 10 constrained airports account for 1684 hours of the 2167 hours of total delay listed in Table 9; that is 78% of the total delay due to airports.

Table 16. Allocation of Airport Delay by Cause for 2030 Scenario with 2030 Advanced ATC Airport and Unconstrained Airspace Capacities

Airport	ATC_AAR (h)	ATC_ADR (h)	TFM_AAR_ GATE (h)	TFM_AAR_ MAN (h)	TFM_AAR_ INT (h)	Total Airport Source Delay (h)	SECTOR_ CONGST_ GATE (h)	Total Delay (h)
KJFK	114.0	191.3	356.7	65.8	26.1	753.8	0.0	753.8
KDCA	26.6	56.5	207.8	16.2	6.0	313.1	0.0	313.1
KATL	34.6	62.0	43.3	15.5	0.2	155.6	0.0	155.6
KEWR	22.4	56.0	24.4	13.6	3.3	119.7	0.0	119.7
KLGA	23.4	43.5	28.1	6.5	1.9	103.5	0.0	103.5
KBWI	13.5	25.5	24.6	3.6	0.2	67.5	0.0	67.5
KSFO	13.5	23.6	10.0	6.8	0.2	54.1	0.0	54.1
KPHX	8.3	33.8	2.3	1.3	0.2	45.8	0.0	45.8
KCLT	7.9	27.8	2.5	0.5	0.0	38.8	0.0	38.8
KMSP	7.8	22.8	0.7	0.5	0.1	31.9	0.0	31.9

Figure 10 shows that at KJFK, demand exceeds capacity for a sustained period of several hours for the 2030 scenario. This is with an increase in VMC capacity to 107 operations per hour from the current capacity of approximately 94 per hour. The resulting delays average close to 14 minutes with 44 flights delayed more than 1 hour. This is in perfect weather; the 2030 IMC estimated capacity is 94 operations per hour, so with the same demand delays would be significantly longer. The chart only shows delays taken at KJFK; that is 404 hours in total. KJFK is the cause of almost 754 hours of total delay, Table 16, so the additional 350 hours caused by constraints at KJFK are taken at other airports or in-flight.

An analysis by Neitzke and Guerreiro (reference 2) determined that the maximum theoretical capacity at KJFK is as high as 166 operations per hour. This is assuming no constraints other than the need to maintain single occupancy of the runways and safe separation using current standards. In reality, other constraints include using standard routes, avoiding traffic streams from proximate airports and restricted airspace, noise etc. Ignoring all constraints other than physical limits was intentional. The purpose of the reference 2 study was to determine how much capacity remains at KJFK beyond current day utilization. With advanced technologies and procedures, some reasonable proportion of the remaining theoretical capacity could be used in the future. Figure 10 shows that for the projected 2030 demand a capacity of around 140 to 145 operations per hour is sufficient to meet the demand and provide some spare capacity to maintain low delays. According to reference 2, this is theoretically feasible without adding runways or otherwise changing the runway layout at KJFK. Given the limited land available at or near KJFK, major changes may be infeasible or very costly. Beyond 2030 as demand exceeds the maximum achievable capacity, other options such as using larger

aircraft or rerouting passengers that are using KJFK as a transfer hub to alternative hubs may be necessary to ensure low delays.

Figure 11 shows that at KDCA demand exceeds or is close to assumed VMC capacity of 67 operations per hour for a sustained period of several hours for the 2030 scenario. The resulting delays average slightly more than 7 minutes with four flights delayed more than 1 hour. This is in perfect weather; the 2030 IMC estimated capacity is 64 operations per hour, so with the same demand delays would be significantly longer. In addition to the 132 hours of delay taken at KDCA, an additional 181 hours of delay caused by constraints at KDCA are taken at other airports or in-flight. Regulations limit operations at KDCA to nominally 62 operations per hour. (Although, note that the baseline 2012 data has 70 operations and the FACT3 based data for 2030 has 67 operations). Even if operations were unregulated, the runway layout at KDCA is not conducive to significantly increased operations; it has a short runway (4991 feet) that cannot be used by many commercial passenger aircraft and the other two runways (5204 feet and 7169 feet) intersect so limiting utilization. In addition, KDCA currently has 44 gates; that is insufficient to accommodate significantly increased demand.

The KDCA chart shows a sudden peak in delays, reaching 123 minutes at hour 19 of the simulation. This appears anomalous so requires explanation. Investigation shows that the peak is the result of delays to 3 flights departing from KDCA to KJFK. Congestion at KJFK cause the delay, not inadequate capacity at KDCA during this time period, see hour 19 of Figure 10. In addition, there are four arrival operations with almost no delay at KDCA during hour 19. The calculated average delay for the seven operations is 122.9 minutes confirming that the chart is correct.

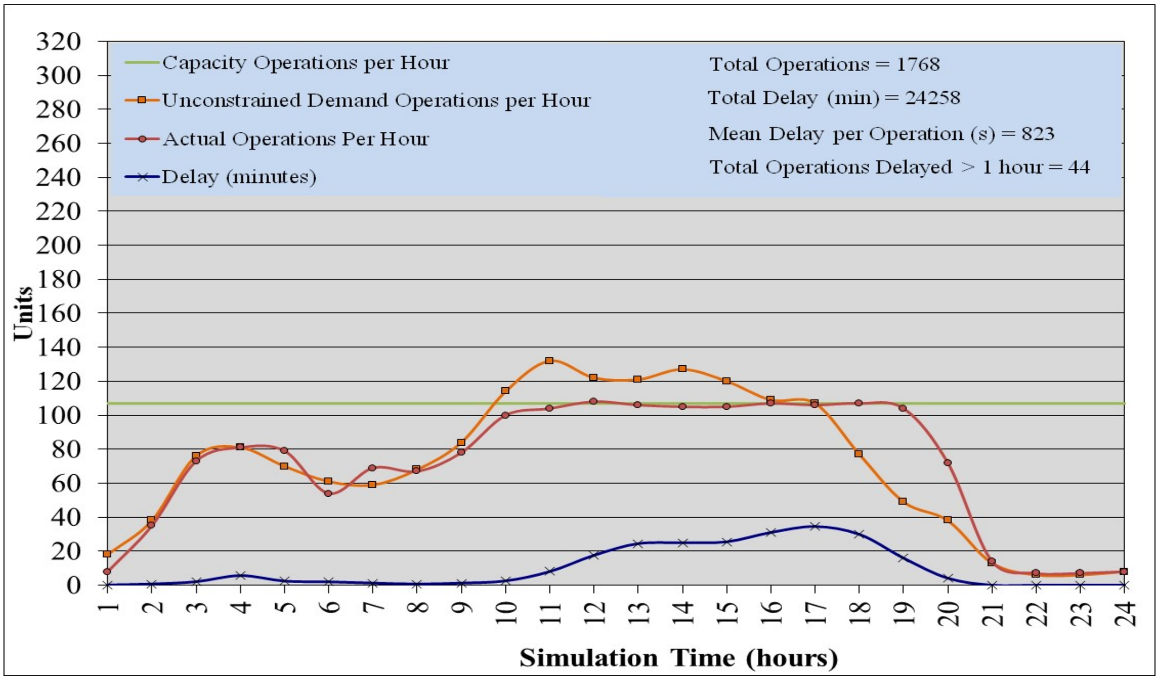

Figure 10. KJFK Operations and Mean Hourly Delay per Operation for 2030 Scenario

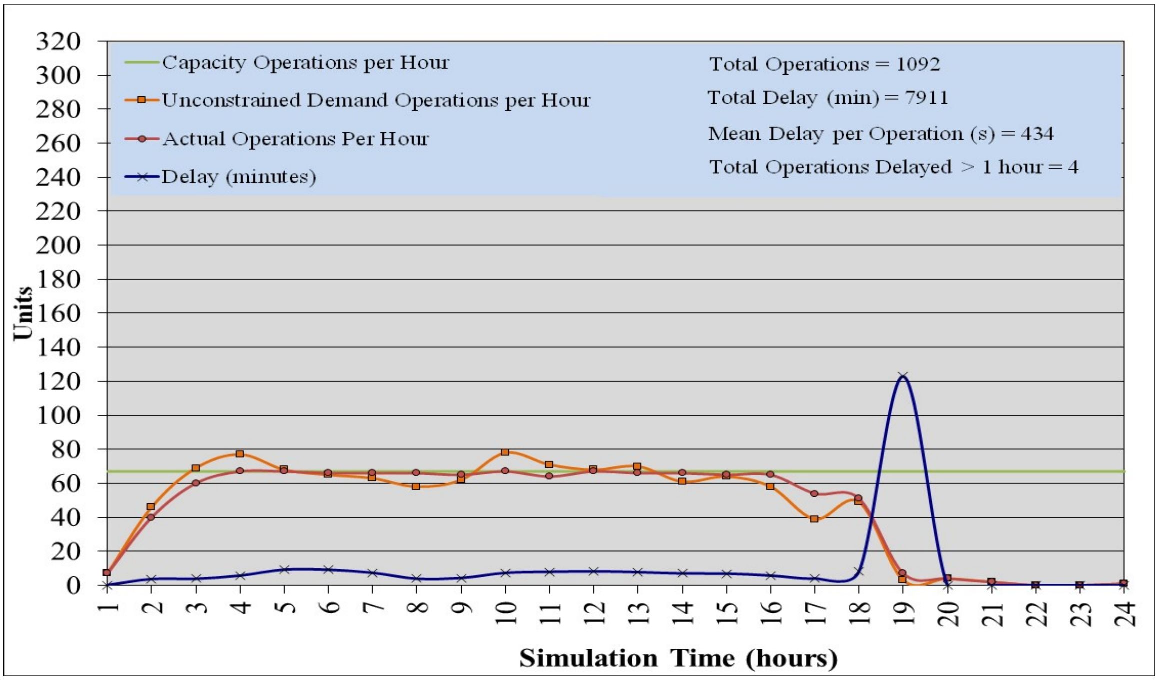

Figure 11. KDCA Operations and Mean Hourly Delay per Operation for 2030 Scenario

Sectors Congestion

Table 9 in the summary section, lists the system-wide sector delay for each of the scenarios. A total of 1739 hours of sector delay occurs for the 2030 scenario using current airports and sector capacities. This is substantially longer than the 33 hours result for the 2012 scenario. Using current day sector boundaries and capacities allows analysis to identify the need for improvements. Increasing airport capacities to the 2030 Advanced ATC values reduces sector delay by a small amount to 1608 hours.

By 2030, major changes to airspace structure and operations are possible. A 20% increase in sector capacities reduces total delay to 266 hours. A 50% increase almost eliminates airspace congestion in the 930 sectors modeled in ACES. This assumes full sector availability, with no capacity reduction for weather. The values for reduced total delay are for a system-wide increase in capacity. Further analysis later in this section shows that only a small number of sectors require increases in good-weather capacity to meet projected 2030 demand.

With Current Airport and Airspace Sector Capacities

Table 17 shows that delays in the 10 sectors with most congestion are substantial compared to the 2012 scenario delays listed in Table 12. Miami sector ZMA62 causes the most delay, but as cautioned previously more sophisticated TFM than modeled in ACES could potentially alleviate congestion by rerouting traffic.

Table 18 shows that increasing airport capacity alone has a small beneficial effect on airspace congestion. Total sector delay reduces to 1608 hours. The top 10 sectors with most delay account for 1240 hours of the total. That is 77% of the total sector delay, indicating that only a small number of the 930 sectors modeled in ACES require significant increases in capacity.

Table 17. Allocation of Sector Delay by Cause with Current Airports and Airspace Sector Capacities for 2030 Scenario

Sector	SECTOR_CONGST_GATE (h)	SECTOR_CONGST_MAN (h)	SECTOR_CONGST_INT (h)	Total Delay (h)
ZMA62	524.5	2.3	188.2	714.9
ZBW02	142.2	0.9	3.1	146.2
ZMP11	81.9	5.8	13.2	100.8
ZLC41	74.6	7.6	1.4	83.7
ZNY75	55.0	6.6	1.8	63.4
ZBW20	52.4	1.5	3.4	57.3
ZLA36	38.4	6.1	0.0	44.5
ZLA39	33.5	6.7	0.0	40.1
ZME43	34.0	5.5	0.0	39.5
ZLC20	19.4	5.1	5.1	29.7

Table 18. Allocation of Sector Delay by Cause with 2030 Advanced ATC Airports and Current Airspace Sector Capacities for 2030 Scenario

Sector	SECTOR_CONGST_GATE (h)	SECTOR_CONGST_MAN (h)	SECTOR_CONGST_INT (h)	Total Delay (h)
ZMA62	506.6	3.0	188.1	697.6
ZBW02	124.5	0.8	1.1	126.4
ZMP11	76.3	5.4	12.5	94.2
ZBW20	68.8	1.9	4.9	75.5
ZLC41	65.6	7.2	1.3	74.1
ZLA36	41.2	6.3	0.0	47.5
ZLA39	32.7	7.3	0.0	40.0
ZME43	34.6	4.5	0.0	39.1
ZLC20	17.1	5.5	5.0	27.6
ZAB67	17.2	2.7	0.1	20.0

With 2030 Advanced ATC Airport and Increasing Airspace Sector Capacities

Table 19 and Table 20 show the effect of increasing system-wide sector capacities by 20% and 50% respectively. Increasing capacities by 20% reduces delays significantly leaving only Miami sector ZMA62 as the apparent cause of significant delay. Increasing capacities by 50% virtually eliminates delays, only ZMA62 has a noticeable delay. Rerouting some flights at times of peak congestion may eliminate remaining congestion at ZMA62.

Table 19. Allocation of Sector Delay by Cause with 2030 Advanced ATC Airport and +20% Airspace Sector Capacities for 2030 Scenario

Sector	SECTOR_CONGST_GATE (h)	SECTOR_CONGST_MAN (h)	SECTOR_CONGST_INT (h)	Total Delay (h)
ZMA62	124.9	1.6	58.0	184.5
ZMP11	5.5	2.8	0.4	8.7
ZBW02	7.6	0.1	0.1	7.8
ZLA36	3.8	1.6	0.0	5.4
ZBW20	4.5	0.4	0.4	5.4
ZLC41	2.7	1.6	0.1	4.3
ZMP20	2.6	1.1	0.0	3.7
ZME43	2.6	1.1	0.0	3.7
ZID76	2.3	0.3	0.2	2.8
ZHU26	1.4	0.7	0.1	2.2

Table 20. Allocation of Sector Delay by Cause with 2030 Advanced ATC Airport and +50% Airspace Sector Capacities for 2030 Scenario

Sector	SECTOR_CONGST_GATE (h)	SECTOR_CONGST_MAN (h)	SECTOR_CONGST_INT (h)	Total Delay (h)
ZMA62	6.9	0.7	2.1	9.7
ZMP11	0.4	0.5	0.0	0.9
ZMP20	0.3	0.3	0.0	0.6
ZID76	0.3	0.2	0.0	0.5
ZNY55	0.4	0.0	0.0	0.4
ZBW20	0.2	0.0	0.1	0.4
ZHU37	0.3	0.0	0.0	0.4
ZLA36	0.2	0.1	0.0	0.3
ZID91	0.1	0.2	0.0	0.3
ZDV07	0.3	0.0	0.0	0.3

Effect of Passenger Choice on Congestion

Passengers respond to increased flight segment times by seeking alternative modes or routes where feasible, as described in Influence of Increased Travel Times on Passenger Choice. The results discussed in this section are for the year 2030 scenario taking into account the influence of delays, with 2030 Advanced ATC Airports and Unconstrained Airspace Capacities.

Figure 12 below shows that mean delay per flight reduces to 103 seconds, from 127 seconds; that is 19% compared to the same scenario without increased travel times shown by Figure 9. There is a significant reduction in the number of flights delayed for more than 1 hour, now 92 compared to 209. This is with just 131 fewer flights in ACES NAS wide. (Note that the total flight numbers flown in ACES do not exactly match the total in Table 6 due to ACES rejecting a small number of flights as explained previously). The reduction in delay may seem disproportionate to the small reduction in flights, but these flights are lost from the most congested routes as analyzed later in this section. In addition, some passengers choose less congested air routes; some flight segments have an increase in flights, while others show a loss, so the aggregate change does not show the complete effect.

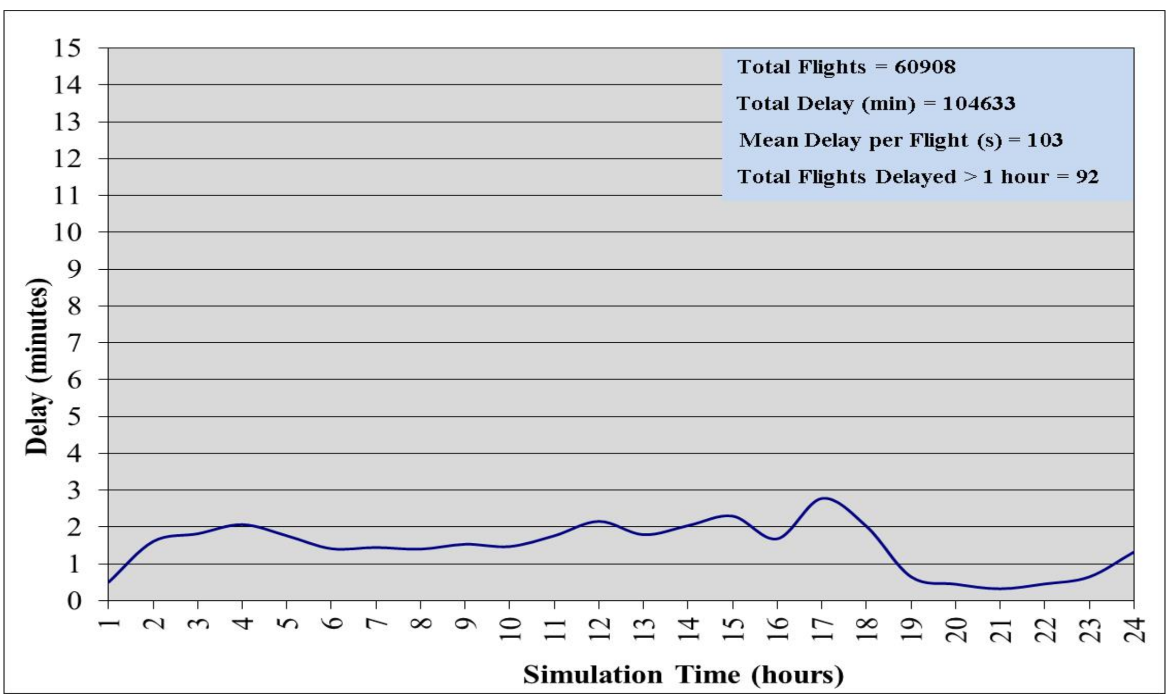

Figure 12. System-Wide Mean Hourly Delay for 2030 Scenario with Influence of Delays

Table 21 lists the 10 airports with most delay. The table shows the delay at the point taken, not allocated to the root cause. This table is directly comparable to Table 15. Most of the congested airports show reduced operations and delay with the largest reductions occurring at KJFK and KDCA.

Table 21. Airport Delay for 2030 Scenario with Influence of Delays

Airport	Total Delay (h)	Difference Table 15	Total Operations	Difference Table 15	Mean Delay per Operation (s)	Difference Table 15
KJFK	314.2	90.1	1693	75	668	155
KATL	126.4	11.3	3395	27	134	10
KEWR	104.3	-4.1	1674	8	224	-10
KLGA	90.2	6	1341	-7	242	17
KDCA	85.3	46.6	1001	91	306	128
KBOS	54.7	30.1	1404	3	140	76
KBWI	54.3	3.6	1031	1	189	13
KCLT	48.1	5.1	1954	-16	88	10
KSFO	44.3	0.4	1530	7	104	0
KPHX	40.9	N/A	1597	N/A	92	N/A

Table 22 shows airport delays allocated by cause. This table is directly comparable to Table 16. KJFK and KDCA combined cause almost 500 hours less delay, 32% less, due to passengers avoiding these airports. Domestic passenger enplanements at KJFK are 13.2% less and at KDCA 10.5% less, as listed in Table 5.

Table 22. Allocation of Airport Delay by Cause for 2030 Scenario with Influence of Delays

Airport	ATC AAR (h)	ATC ADR (h)	TFM AAR GATE (h)	TFM AAR MAN (h)	TFM AAR INT (h)	Total Airport Source Delay (h)	SECTOR CONGST GATE (h)	Total Delay (h)	Total Delay Difference Table 16 (h)
KJFK	91.9	151.9	192.4	53.6	15.6	505.4	0.0	505.4	248.4
KATL	34.3	64.3	43.2	15.2	0.1	157.1	0.0	157.1	-1.5
KEWR	21.1	64.9	26.1	13.3	3.8	129.2	0.0	129.2	-9.5
KLGA	27.3	48.6	35.3	7.3	2.7	121.1	0.0	121.1	-17.6
KDCA	17.7	39.0	33.7	5.8	1.4	97.7	0.0	97.7	215.4
KBWI	14.5	27.6	30.0	4.4	0.3	76.9	0.0	76.9	-9.4
KSFO	13.2	23.4	11.8	6.6	0.3	55.3	0.0	55.3	-1.2
KCLT	9.1	30.9	3.8	0.8	0.0	44.6	0.0	44.6	-5.8
KPHX	7.9	31.5	1.1	0.8	0.1	41.4	0.0	41.4	4.4
KMSP	7.4	24.0	1.7	1.1	0.1	34.4	0.0	34.4	-2.5

Figure 13 shows a reduction of delay at KJFK of 90.1 hours, that is 22% compared to Figure 10. This is for a reduction of 75 KJFK operations, a 4% reduction. The chart only shows delays taken at KJFK; that is 314 hours in total. KJFK is the cause of 505 hours of total delay, Table 22, so the additional 191 hours caused by constraints at KJFK are taken at other airports or in-flight.

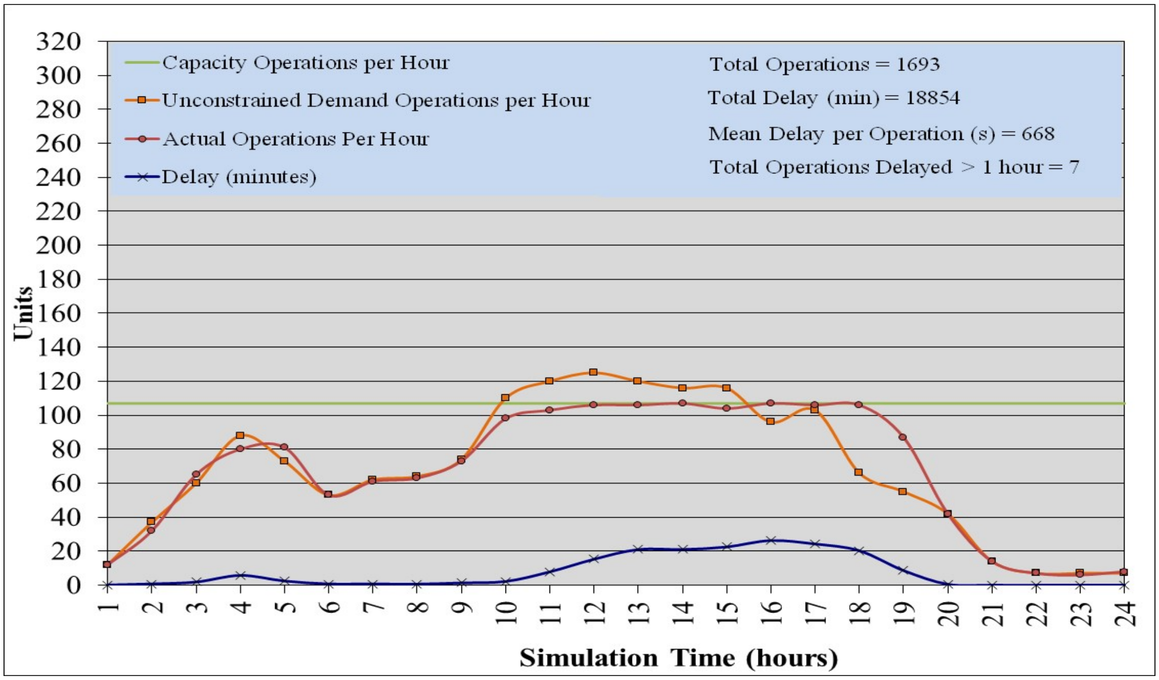

Figure 13. KJFK Operations and Mean Hourly Delay per Operation for 2030 Scenario with Influence of Delays

Table 23 shows the flight segments to and from KJFK that show the most reduction in delays. The KBOS to KJFK flight segment shows a 45% reduction in total delay for a 15% reduction in the number of flights. This reduction in delay is only partly attributable to the 3-flight reduction on this route. Delays are shorter overall due to the reduction in total operations at KJFK.

Table 23. KJFK Difference in Delays and Operations for 2030 Scenario Flight Segments with Influence of Delays

Departure Airport	Arrival Airport	2030 Scenario		2030 Scenario with Influence of Delays		Difference Between Scenarios	
		Total Delay (h)	Number of Departures	Total Delay (h)	Number of Departures	Total Delay (h)	Number of Departures
KBOS	KJFK	43.9	20	24.2	17	19.7	3
KMVY	KJFK	18.1	5	5.9	3	12.3	2
KORD	KJFK	28.8	16	17.4	15	11.4	1
KRDU	KJFK	21.0	11	10.8	10	10.3	1
KIAD	KJFK	19.9	11	9.8	9	10.1	2
KACK	KJFK	14.2	6	6.2	4	8.0	2
KBWI	KJFK	14.4	5	6.5	4	7.9	1
KBTV	KJFK	13.5	6	5.8	4	7.8	2
KDCA	KJFK	21.6	9	1.7	7	6.6	2
KBDL	KJFK	8.1	2	15.0	1	6.0	1
KJFK	KDCA	8.9	9	1.7	6	7.2	3
KJFK	EGLL	9.9	33	7.6	33	2.3	0
KJFK	LFPG	5.2	15	4.0	15	1.2	0
KJFK	KLAX	7.6	36	6.6	36	1.0	0
KJFK	KBOS	3.0	18	2.1	16	0.9	2
KJFK	SBGR	3.3	12	2.4	12	0.9	0
KJFK	LEMD	3.8	10	3.0	10	0.8	0
KJFK	KORD	3.3	14	2.5	13	0.8	1
KJFK	KCMH	1.5	5	0.8	4	0.8	1
KJFK	KPDX	1.8	6	1.1	5	0.7	1

Figure 14 show a reduction in delay at KDCA of 46.6 hours, that is 35% compared to Figure 11. This is for a reduction of 91 KDCA operations, an 8% reduction. Also of note is the sudden peak in delays at hour 19 in Figure 11 is no longer

present. As explained previously this was due to 3 flights departing from KDCA to KJFK. Congestion at KJFK caused 14.3 hours of the total ground hold delay at KDCA to these 3 flights. Fewer flights arriving at KJFK due to passengers avoiding KJFK reduces ground holds at KDCA. The chart only shows delays taken at KDCA; that is 85 hours in total. KDCA is the cause of 215 hours of total delay, Table 22, so the additional 130 hours caused by constraints at KDCA are taken at other airports or in-flight.

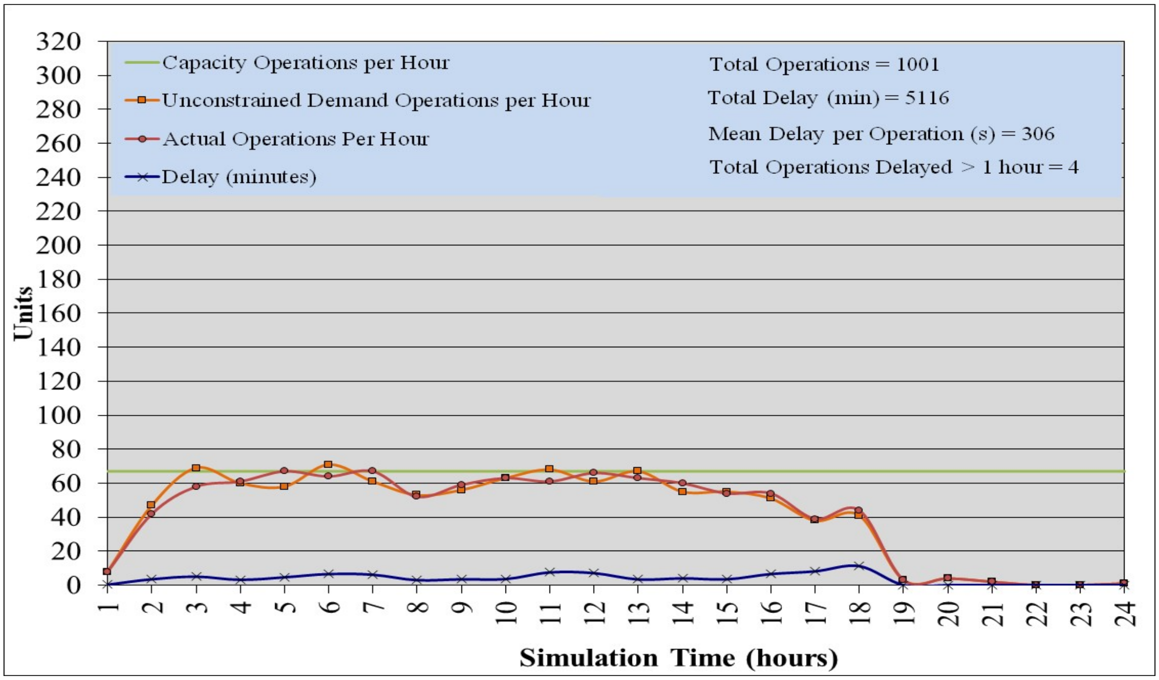

Figure 14. KDCA Operations and Mean Hourly Delay per Operation for 2030 Scenario with Influence of Delays

Table 24 shows the flight segments to and from KDCA that show the most reduction in delays. The KLGA to KDCA flight segment shows a 66% reduction in total delay for a one-flight reduction, that is 3%. This reduction in delay is only partly attributable to the one-flight reduction on this route. Delays are shorter overall due to the reduction in total operations at KDCA by 91 flights.

Table 24. KDCA Difference in Delays and Operations for 2030 Scenario Flight Segments with Influence of Delays

Departure Airport	Arrival Airport	2030 Scenario		2030 Scenario with Influence of Delays		Difference Between Scenarios	
		Total Delay (h)	Number of Departures	Total Delay (h)	Number of Departures	Total Delay (h)	Number of Departures
KLGA	KDCA	23.0	34	7.7	33	15.3	1
KBOS	KDCA	18.1	29	4.4	27	13.8	2
KORD	KDCA	15.5	27	2.5	27	13.1	0
KATL	KDCA	14.5	25	3.3	25	11.2	0
KJFK	KDCA	8.9	9	1.7	6	7.2	3
KCLT	KDCA	9.7	16	2.7	14	7.0	2
KDTW	KDCA	8.7	13	2.1	12	6.7	1
KRDU	KDCA	7.3	15	1.3	12	6.0	3
KMCO	KDCA	7.3	14	1.9	13	5.5	1
KPHL	KDCA	6.4	9	1.2	8	5.1	1
KDCA	KJFK	21.6	9	15.0	7	6.6	2
KDCA	KATL	4.0	25	3.0	25	1.0	0
KDCA	KORD	3.6	28	2.8	28	0.8	0
KDCA	KBOS	2.8	28	2.0	27	0.7	1
KDCA	KBDL	1.1	11	0.4	9	0.6	2
KDCA	KCLT	1.6	15	1.0	14	0.6	1
KDCA	KRDU	1.5	14	0.9	12	0.6	2
KDCA	KCVG	1.0	12	0.4	10	0.6	2
KDCA	CYYZ	1.3	13	0.8	13	0.5	0
KDCA	KJAX	0.9	6	0.4	5	0.5	1

A significant limitation of this analysis of congestion effects is that the methodology to create flight schedules by scaling a baseline does not allow removal of flights from that baseline. This means that on segments with a small number of passengers and correspondingly few daily flights, the flight schedule may be unchanged even though the number of passengers substantially reduces. Even for routes with many flights per day, the number of flights does not reduce below the baseline, even though the reduction in passengers may warrant this.

In addition, TSAM does not use a mode-choice methodology for estimating growth in international flights or domestic legs of international flights, so the effects of congestion cannot be determined for these categories. Therefore, longer trip times apply only to internal domestic flights. For example, 44% of the flights at KJFK are international for the year 2030 scenario, an increase from 34% in 2012.

Both of the above factors lead to an underestimation of the effects of delay on the schedule.

Conclusions

The objective of this study is to identify choke points in the current and future NAS. The results are for good weather, with all airports operating in VMC. The study required traffic demand and NAS capacities representative of the current system and projected future system. The results are from ACES for 24 hours of simulated traffic.

An ACES traffic scenario representative of current demand requires a baseline day of recorded traffic. The day chosen for this study was 25 July 2012, since this day had mostly good weather NAS-wide with a high volume of traffic. The future date chosen for NAS analysis was the year 2030. The ACES future scenarios used TSAM projections to grow the baseline demand, with two alternative fuel price forecasts. An additional variation of the 2030 demand scenario, takes into account the influence of delays on passenger choice.

FAA supplied data is used as the basis for estimates of current and future airport capacities and current sector definitions and capacities. Future sector capacities are simply scaled by 20% and 50% for this study. In addition, some simulation experiments used unconstrained airspace.

Current System Choke Points

The current NAS baseline scenario has an average delay per flight of 53 seconds with total NAS wide delay of 656 hours. Of this total, the majority of delay is due to congestion at a few airports, only 33 hours of delay is due to airspace congestion. There are no flights with delays of more than 1 hour.

The airports responsible for most delay are KATL and KLGA. They are the root cause of 62 and 51 hours total of system-wide delay respectively.

KATL has 59 hours of delay to operations at the airport, equating to 85 seconds mean delay per flight. An insignificant 3 hours of delay caused by KATL occurs on the ground at other airports or in flight. KATL has some spare capacity, but peaks in either arrival or departure demand cause some overloading at some times of the day.

KLGA has 49 hours of delay to operations at the airport, equating to 166 seconds mean delay per flight. KLGA is the root cause of 10 hours of additional delay, not taken at KLGA. KLGA is operating near capacity, but mostly still operates with low delays in good weather.

Neither KATL nor KLGA is currently a significant choke point in VMC, as shown by the small amount of delay caused by these airports to other airports in the system.

A conclusion from this study is that in perfect weather conditions, with current day available airport and sector capacities, there are no significant choke points, according to results from ACES simulation. A few airports are operating near capacity, and for those, significant delays will occur under IMC conditions. The 10 airports in order of most delay in VMC are KATL, KLGA, KPHX, KCLT, KJFK, KDCA, KORD, KEWR, KMSP and KLAX.

Future System Projected Choke Points

The conclusions regarding future choke points are subject to forecast uncertainty in demand and airline operations. Demand for airline travel may be significantly higher or lower than forecast if economic growth is significantly higher or lower than expected. Major air carriers are likely to make changes to their networks and hubs (some hubs could grow, others shrink). New carriers may arise, others may merge or cease operations. The effect is, some of these airports will be more congested than predicted, and others less so.

The primary 2030 scenario uses the FAA's fuel price forecast and future airport capacities. The 2030 airport capacities with "Advanced ATC" assumptions represents Operational Improvements that are part of FAA's NextGen plans and concepts. There are additional improvements that NASA and other researchers are investigating that are not included.

A simulation, using current airport and sector capacities with 2030 demand, shows very large delays as expected, since this scenario has 37% more total flights and 47% more scheduled airline flights than the current NAS baseline. Using current capacities is not a realistic expectation of the available capacity in 2030; rather it allows analysis of the causes of delay, identifying shortfalls in capacity.

The results from ACES confirm that without capacity improvements, the NAS cannot support the 2030-projected demand. Results from simulation show an average delay per flight of 349 seconds with total NAS wide delay of 5,929 hours. Over 1,000 flights experience delays of more than 1 hour. Of this total delay, the majority is due to airport congestion, but a substantial 1,739 hours is due to airspace congestion. KJFK is now the most overloaded airport with almost 33 minutes mean delay per flight. The 10 airports in order of most delay in VMC are KJFK, KATL, KLGA, KEWR, KMIA, KDCA, KPHX, KCLT, KFLL and KBWI.

A scenario using unconstrained airspace, to isolate the effects of airport choke points and 2030 Advanced ATC airport capacities shows that delays still exceed the current day NAS delays. This scenario has an average delay per flight of 127 seconds with total NAS wide delay of 2,167 hours. Total delay is more than three times longer than the current NAS baseline delay. The number of flights with more than 1-hour delay is 209; there were no flights of more than 1-hour delay in the current day perfect weather baseline. This indicates that although the airport capacity improvements expected by 2030 significantly improve NAS performance, some capacity shortfall still exists, even in VMC.

The main choke point airports are KJFK, KDCA, KATL, KEWR, KLGA; each causes more than 100 hours of system-wide delay in the 24 hours of simulated operations. KJFK is the most overloaded airport causing 745 hours of delay with KDCA second, causing 313 hours of system-wide delay. This is with unconstrained demand; in reality the number of future operations may be limited by regulation as is the case today or the airlines may restrict operations to avoid

excessive delays. The effect of insufficient capacity will be a balance between increased delay and unsatisfied demand.

The sensitivity of the 2030 scenario delay to sector capacity is investigated by scaling the current NAS baseline capacities by 20% and then by 50%. ACES results show a reduction in sector delays by a factor of more than six from 1739 hours total, to 266 hours for a 20% increase in sector capacity and are reduced to a negligible 14 hours for a 50% increase in capacity.

Furthermore, the 10 sectors with most delay account for 86%, that is 223 hours of the 266 hours total delay for the 20% increase case. Of those, the sector with most delay, Miami sector ZMA62 accounts for 184 hours. Increasing sector capacities by 50% reduces the ZMA62 delay to 9 hours. Rerouting some flights at times of peak congestion may eliminate remaining congestion at ZMA62. This result is for perfect weather.

A conclusion from this study is that the 2030 Advanced ATC airport capacities are not sufficient to meet 2030 demand even in VMC, although the improvements greatly reduce delays that would otherwise occur. KJFK, KDCA, KATL, KEWR, KLGA are the most significant choke points. The 10 airports in order of most delay in VMC are KJFK, KDCA, KATL, KEWR, KLGA, KBWI, KSFO, KPHX, KCLT and KMSP. A 20% to 50% increase in sector capacity at the 10 most congested sectors, reduces sector congestion to negligible amounts in perfect weather, according to ACES results.

A scenario using the EIA fuel price forecast shows a 12% reduction in total delay compared to using the FAA's fuel price, for a 2% reduction in the total number of flights, with a corresponding 4% reduction in scheduled airline flights. This result is for simulation using 2030 Advanced ATC airport capacities and current NAS sector capacities. Delay due to airport constraints reduces by 16% and sector congestion by 6%. Using current sector capacities allows observation of the effects of a small reduction in flights on sector congestion. (Comparison with the 20% or greater increase in sector capacities case gives little insight since sector delays are very low).

Passengers will avoid congested routes and airlines may charge more on high demand routes where there is little capacity to expand service, also encouraging some passengers to seek alternatives. A scenario taking into account the influence of delays on passenger choice shows a 20% reduction in delays for a 0.6% reduction in airline passenger flights. This result is for simulation using 2030 Advanced ATC airport capacities and unconstrained airspace capacities. The disproportionate reduction in delay indicates that delays are highly sensitive to passenger choice. The delay reduction has two causes; passengers switching to an alternative mode; and switching to less congested flight routes. The aggregate change in flights does not give full insight into the reasons for the reduction in delays.

A conclusion from this study is that a small reduction in flights can have a disproportionate effect on reducing delays once resources start to become overloaded. In addition, changes to the routing or scheduling of flights to avoid congested resources or peak times can be very beneficial to the NAS.

Since the results are quite sensitive to changes, some of these airports will be more congested than predicted and others less so. All major air carriers are likely to make further changes to their networks/hubs (some hubs could grow, others shrink) that are difficult to forecast.

Notes: The original scope of this study included the effects of weather. The re-organization of NASA Aeronautics Programs for FY15 led to a reduction in scope to good-weather conditions to ensure the study completed in FY14. The airport capacity values used in this report are based on data provided by the FAA prior to publication of the FACT3 report, reference 2. The final airport capacity values differ slightly from the pre-release data but are broadly similar. The "Advanced ATC" airport capacity values are not included in the published FACT3 report, since the report only contains projections for the year 2020.

References

1. FACT3: Airport Capacity Needs in the National Airspace System, Federal Aviation Administration, January 2015, plus companion report Airport Capacity Profiles, July 2014.

2. Exploration of the Theoretical Physical Capacity of the John F. Kennedy International Airport Runway System, Kurt W. Neitzke and Nelson M. Guerreiro, NASA Langley Research Center, AIAA, SciTech January 2014

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14. ABSTRACT
This report identifies choke points in the current and future National Airspace System (NAS). Choke points refer to any areas that constrain actual demand in current and projected future operations. This analysis uses Transportation Systems Analysis Model (TSAM) projections of future demand developed by NASA in collaboration with Virginia Polytechnic Institute. The future demand projections from TSAM are used in NASA's Airspace Concepts Evaluation System (ACES) simulation, to evaluate sources of delay using current and future (year 2030) airport capacity values derived from FAA supplied data.

15. SUBJECT TERMS
Airport capacity; Airspace simulation; Choke points; Demand modeling; National airspace System capacity

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